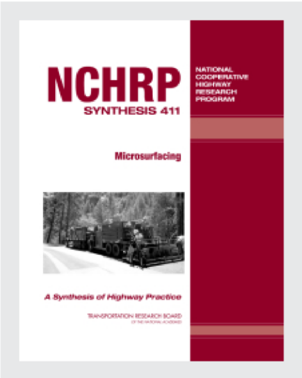

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 411

Microsurfacing

A Synthesis of Highway Practice

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SUBSCRIBER CATEGORIES
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Cover figure: Continuous front-loaded, self-propelled microsurfacing machine and crew (*courtesy*: Rusty Price, Intermountain Slurry Seal, Inc.).

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-05, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jo Allen Gause
Senior Program Officer
Transportation Research Board

This study gathers information on the use of highway microsurfacing treatments by transportation agencies in the United States and Canada. Microsurfacing is a polymer-modified cold-mix surface treatment that can remedy a broad range of problems on today's highways. The report identifies and discusses practices reported as effective by transportation agencies in microsurfacing project selection, design, contracting, equipment, construction, and performance measures.

Information used in this study was acquired through a review of the literature, a survey distributed to maintenance engineers at all U.S. state departments of transportation (DOTs) and Canadian provincial transportation agencies, evaluation of all 50 state DOT microsurfacing specifications as well as the one used by the U.S. Federal Lands Highway Division, and case studies of six microsurfacing projects from five U.S. states and one Canadian province.

Douglas D. Gransberg, Iowa State University, Ames, Iowa, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

MICROSURFACING

SUMMARY

Microsurfacing is a widely used tool for both pavement preservation and preventative maintenance. It is generally considered to be a highly specialized process, and public highway agencies often depend on the experience of the microsurfacing contractor and its emulsion supplier for both design and construction. This report documents the state of the practice of this pavement preservation and maintenance tool and identifies critical knowledge gaps that could be filled by additional research. The objective of this synthesis is to identify current practices in microsurfacing that highway maintenance practitioners report as effective in addressing specific pavement preservation and maintenance problems. To accomplish the stated objective, the consultant used four instruments to collect and process data:

1. A comprehensive review of the literature.
2. A survey distributed to maintenance engineers at all state departments of transportation (DOTs) and Canadian provincial transportation agencies. The DOT survey achieved an 88% response rate; the Canadian survey response rate was 93%.
3. Evaluation of all 50 state DOT microsurfacing specifications as well as the one used by the U.S. Federal Lands Highway Division (FLHD).
4. Case studies of six microsurfacing projects from five U.S. states and one Canadian province.

Although microsurfacing is the specific subject of the report, the review of literature and state DOT specifications found that microsurfacing and slurry sealing were often included together in the same specifications section, many times with little or no differentiation between the two treatments. Only 18 of 51 standard specifications included a section specifically titled "microsurfacing." Other agencies had sections with titles such as "Cold-Laid Latex Modified Emulsion Pavement Course" (Pennsylvania) and "Paver-laid Surface Treatment" (Alabama). An example of this microsurfacing terminology issue is the FLHD specification, which states in Section 410—Slurry Seal: "This work consists of applying an *asphalt slurry seal or a polymer modified microsurfacing mix* on an existing pavement surface" (2003, italics added). The word "microsurfacing" is found only in this sentence and the remainder of the section does not differentiate between the two treatments, which gives the two the same set of specifications. Therefore, an effort to standardize the terminology in this area would be beneficial. The International Slurry Surfacing Association advocates categorizing both as "Slurry Systems" while maintaining the following distinction: microsurfacing always contains a polymer-modified emulsion that is designed to break chemically and, as a result, can be turned over to traffic within a short period of time (usually about an hour after application).

Second, the survey found that few agencies have a formalized approach to their microsurfacing program that evaluates the potential impact to the environment. This may be because pavement preservation is inherently green based on its focus on keeping good roads in a condition where they do not need to consume more energy and raw materials to restore their serviceability. Microsurfacing has a smaller environmental footprint than other treatments, as described by Takamura et al. in 2001 and Chelovitz and Galehouse in 2010. Its rapid curing times provide a means to minimize work zone delays and, as a result, accrue the benefits of enhanced safety. Nevertheless, with the current focus on environmental responsibility in trans-

portation, a more robust policy toward assessing the environmental footprint of pavement preservation and maintenance during the planning and treatment selection process is warranted.

Chapter nine provides a number of conclusions that are supported and documented in the report. The most significant of these are:

- Microsurfacing is best suited to address rutting, raveling, oxidation, bleeding, and loss of surface friction. Microsurfacing does not perform well if it is applied to structurally deficient pavements. This makes project selection the most important step in the microsurfacing design process with regard to impact on the final performance of the microsurfacing itself.
- The majority of the survey respondents assign the contractor the responsibility for developing the job mix formula (i.e., the mix design). The majority of the same population rated their microsurfacing project performance as satisfactory.
- Most of the U.S. and Canadian agencies believe they do not have an adequate level of competition among qualified microsurfacing contractors for their programs. This may be because many agency microsurfacing programs do not consistently advertise a sufficient amount of work each year for interested contractors to invest in the technical capacity and equipment necessary to competitively bid on these contracts.
- Most agencies do not prequalify microsurfacing bidders. This may be because the pool of competent and qualified contractors is inherently shallow. Contractor experience was also cited as the most important factor affecting microsurfacing quality. This indicates that there is a need to develop a training and certification program at the national level.
- Microsurfacing has a smaller environmental footprint than most pavement preservation and maintenance treatments. Additionally, its ability to return the road to full-speed traffic in roughly 1 h minimizes user work zone delays and enhances traffic safety. These two intangible benefits may justify its use over other practical options that are of marginally lower cost.

This report documents a number of effective practices identified in the course of the study. An effective practice is defined as a practice found in the literature and then confirmed as in use and effective by survey responses or the specification content analysis. The synthesis identified two effective practices in microsurfacing project selection, three in design, four in contracting, and six in construction, as well as three more that came from the case study analyses. The most significant are:

- Agencies in northern climates can mitigate potential quality issues induced by a short microsurfacing season by requiring a warranty.
- Making microsurfacing contract packages as large as is practical reduces the unit price and increases the number of lane-miles that can be treated each year.
- Requiring that a test strip of 500 to 1,000 ft (152.4 to 304.8 m) in length be constructed and inspected will allow the agency and the contractor to ensure that microsurfacing equipment is properly calibrated and that any workmanship issues are resolved before full-scale microsurfacing production. If the microsurfacing is scheduled to occur after dark, it is important that the test strip be constructed after dark.
- Microsurfacing can be effectively employed on roads where routine winter snow removal is a factor if the pavement upon which it is placed is structurally sound.

Eight future research projects are suggested to fill critical knowledge gaps. The three most significant research needs are as follows:

- Evaluate the differences in microsurfacing costs and performance in the eight U.S. states that require a warranty versus a similar number and geographical distribution of those that do not.

- Investigate and quantify the environmental benefits of microsurfacing inside the larger set of pavement preservation and maintenance tools. This project would provide hard, factual justification for selecting microsurfacing over a lower-priced option if all other technical considerations were equal.
- The lack of rigorous field tests based on a rational quantification of measurable microsurfacing properties leads to a suggestion for research to develop a suite of field tests that allow an inspector to test the microsurfacing mix after it has been laid as well as tests to identify when the mix has cured to a sufficient degree to open it to traffic without fear of damaging it.

In conclusion, the synthesis found that microsurfacing is being used successfully on a routine basis across North America. It found that agencies were consistently satisfied with its performance and that it is effective in a pavement preservation role if the underlying pavement is structurally sound. To summarize, microsurfacing works well to address rutting, raveling, oxidation, bleeding, and loss of surface friction. If it is applied to the right road at the right time, most agencies expect an effective service life extension of six to seven years.

CHAPTER ONE

INTRODUCTION

INTRODUCTION

Microsurfacing treatments are widely used for both pavement preservation and preventative maintenance. Although there has been extensive research on hot-mix asphalt design and chip seal surface treatments, microsurfacing design and construction continues to depend more on the specialized experience of the microsurfacing contractor and its emulsion supplier than the information developed through agency research and experimentation. Therefore, the need to benchmark the state of the practice and identify those areas where further research will add value to this important pavement preservation and maintenance tool is timely. "Microsurfacing mixtures are made of high-quality aggregate and asphalt emulsion components" (Johnson et al. 2007) as well as mineral filler, water, and polymer modifiers. It is applied cold by means of a special purpose mixing and laying machine. The International Slurry Seal Association (ISSA) categorizes it as a "slurry system," not be confused with slurry seal (ISSA 2010a).

SYNTHESIS OBJECTIVE

The objective of this synthesis is to identify and synthesize current commonly accepted practices for using microsurfacing in highway pavement preservation and maintenance programs. Its focus is on finding commonalities among microsurfacing practices from separate sources of information that have reported good performance and may ultimately be classified as effective practices. Although microsurfacing is specifically the subject of this report, the review of literature and state department of transportation (DOT) specifications found a distinct lack of uniformity in the terminologies used to describe microsurfacing and slurry sealing. Thus, this report will discuss the differences between the two systems and their applications to furnish a better understanding to the reader. Finally, the synthesis seeks to find microsurfacing programs that have been effectively implemented and that document microsurfacing's unique ability to address specific pavement preservation and maintenance problems.

In addition to a literature review, the synthesis is based on data from a recent survey, six case studies, and the content analysis of state DOT microsurfacing specifications. A survey on microsurfacing practices distributed to state and provincial maintenance engineers achieved an 89% overall response rate, which corresponds to responses from 44 U.S. state DOTs and 12 Canadian provincial/territorial ministries of transportation (MOT). A content analysis of microsurfacing specifications from 18 U.S. states was also undertaken. Finally, six case studies from five U.S. states and one Canadian province were conducted to furnish specific information on agency-level microsurfacing successes.

BACKGROUND

Microsurfacing consists of a mixture of polymer-modified asphalt emulsion, graded aggregates, mineral filler, water, and other additives. The mixture is made by a specialized machine and placed on a continuous basis by mixing the materials simultaneously in a pug mill. Figure 1 shows the process in the microsurfacing machine, which results in a free flowing composite material, spread on the underlying pavement using a spreader box. The mixture's consistency permits it to be evenly spread over the pavement, forming an adhesive bond to the pavement. "The mixture contains asphalt emulsion that breaks onto the pavement surface through heterogeneous or homogenous flocculation. Particles of asphalt coalesce into films, creating a cohesive mixture. The mixture then cures, by loss of water, into a hardwearing, dense-graded asphalt/aggregate mixture that is bonded to the existing pavement" (National Highway Institute 2007). Microsurfacing does not enhance the structural capacity of the existing pavement (Smith and Beatty 1999). Hence, it is used as a pavement preservation and maintenance treatment to improve the functional characteristics of the pavement surface and extend its service life.

History

Slurry surfacing originated in the 1930s in Germany, where it was called "micro-asphalt concrete" (ISSA 2010a). It consisted of a mixture of very fine aggregate, asphalt emulsion, and water. This technique for maintaining road surfaces started slurry surfacing development in the rest of the world. In the 1960s, the introduction of improved emulsifiers, continuous flow machines, and set control additives created a technical environment in which the promise for slurry surfacing was realized. "In the mid-1970s, Screg Route, a French company, designed Seal-Gum, a micro-asphalt concrete that was subsequently improved by the German firm Raschig, and marketed in the United States under the trade name 'Ralumac' during the early 1980s" (ISSA 2010a).

Since being introduced into North America, microsurfacing has become a routine tool in the highway pavement manager's

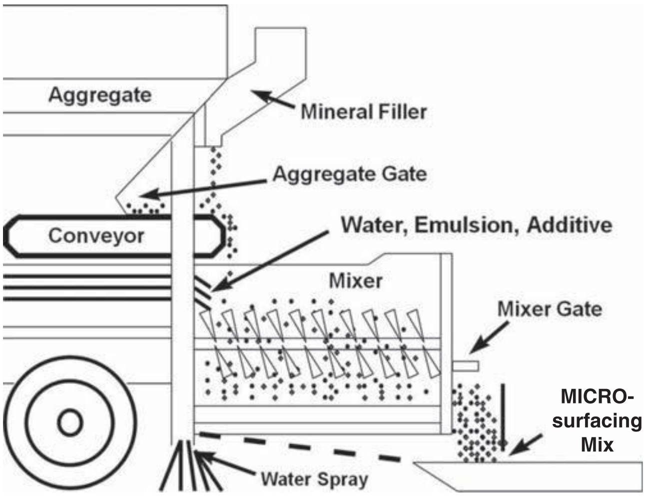


FIGURE 1 Schematic of microsurfacing machine (ISSA 2010a).

pavement preservation and maintenance toolbox. Table 1 shows the FHWA matrix that defines the suite of pavement management planning tasks and where pavement preservation treatments fall within the universe of pavement preservation and maintenance guidelines. One can see that the major feature that separates pavement preservation treatments from the others is that pavement preservation does not increase the strength or capacity of the road. The bold box in Table 1 shows that microsurfacing can be used in three of the activity types: preventive maintenance, routine maintenance, and corrective maintenance. The first two fall within the pavement preservation realm.

1. An example of preventive maintenance would be the use of microsurfacing to cover oxidized or raveled pavement to prevent further deterioration (Labi et al. 2007).
2. Using microsurfacing as a rut filler would be routine maintenance (Jahren et al. 1999).
3. Using it to restore surface friction on a road where skid numbers have fallen below safety minimums is an example of corrective maintenance (Hicks et al. 2000).

Common Applications

Microsurfacing's flexibility to be used across three categories of maintenance is because it is a thin surfacing that can be laid at a thickness of two to three times the size of the largest stone in the mix. The emulsion in the system is polymer-modified with additives that create a chemical break that is largely independent of weather conditions. The emulsion forces water from the aggregate surface during breaking, which allows the newly surfaced road to be opened to traffic within 1 h or less of its application under a range of conditions (Price 2010). Microsurfacing specifications call for high-quality aggregates, fast setting/curing, and stiff emulsion to allow thicker layers to be placed. As a result of the layer thickness, the following extended performance characteristics and applications are possible:

- Correction of minor surface profile irregularities (Bae and Stoffels 2008; Olsen 2008).
- Rut filling (Labi et al. 2007; Olsen 2008).
- Higher durability (Labi et al. 2007; ISSA 2010a).
- Night work or cooler temperatures (Olsen 2008; Caltrans 2009).
- Restoring surface friction to concrete bridge decks (Olsen 2008).

Although it has been reported to seal small surface cracks resulting from thermal changes (Bae and Stoffels 2008), microsurfacing is usually not intended as a crack treatment and will not prevent cracks in the underlying pavement from reflecting through to the surface (Johnson et al. 2007). Research in Minnesota, which is case studied in chapter eight, has shown that using a softer binder shows the potential to reduce the level of reflective cracking (Johnson et al. 2007). Therefore, this option is primarily a preservation treatment to keep good roads in good condition and not an appropriate tool to use on pavements whose structural condition has been compromised.

Environmental Impact

Pavement preservation is inherently green owing to its focus on conserving energy and raw materials, and reducing greenhouse

TABLE 1
MICROSURFACING'S RELATIONSHIP TO PAVEMENT PRESERVATION GUIDELINES

Pavement Preservation Guidelines						Micro-surfacing
	Type of Activity	Increase Capacity	Increase Strength	Reduce Aging	Restore Serviceability	
	New Construction	X	X	X	X	
	Reconstruction	X	X	X	X	
	Major Rehabilitation		X	X	X	
	Structural Overlay		X	X	X	
Pavement Preservation	Minor Rehabilitation			X	X	
	Preventive Maintenance			X	X	X
	Routine Maintenance				X	X
	Corrective (reactive) Maintenance				X	X
	Catastrophic Maintenance				X	

Source: after Geiger (2005).

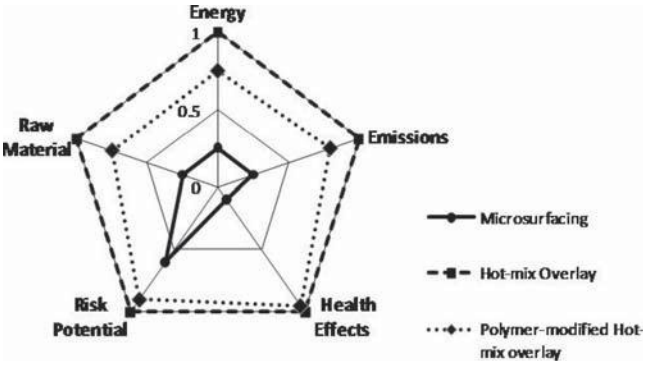


FIGURE 2 Microsurfacing environmental footprint compared with two types of pavement preservation overlays (Takamura et al. 2001).

gases by keeping good roads good (Chehovitz and Galehouse 2010). Microsurfacing's environmental footprint is lower than most common pavement preservation and maintenance treatments (Takamura et al. 2001). Figure 2 is from a study on the environmental impact of several commonly used pavement preservation and maintenance treatments. The study developed "eco-efficiency" indices for the five categories shown in the figure and found that microsurfacing had a substantially lower environmental footprint than the other options (Takamura et al. 2001). This study does not include the reduced greenhouse gas emissions resulting from microsurfacing's ability to greatly reduce traffic delays in work zones (Johnson et al. 2007). Additionally, the "risk potential" and "health effects" categories did not include the reduction in work zone accident risk inherent to microsurfacing (Erwin and Tighe 2008). Therefore, microsurfacing's "true" footprint may be even smaller in relation to hot-mix asphalt options for pavement preservation and maintenance programs. When looking at options to address pavement preservation and maintenance issues, the engineer can use the environmental and safety benefits of microsurfacing as possible justification to offset any marginal increase in construction cost versus other alternatives.

KEY DEFINITIONS

The report uses a number of technical terms in a precise sense that is important for the reader to understand. The technical vocabulary of this field has undergone a radical transformation as new products and new concepts have been developed. The major terminology challenges found in the literature revolve around two major areas. The first is the terms applied to various activities associated with pavement maintenance. The second is the fundamental definition of microsurfacing versus slurry sealing. The lack of uniformity of microsurfacing terminology exists not only in the technical literature but also in the standard specifications of state DOTs in the United States. The specific definitions have been controversial and oftentimes rooted in local construction jargon. The terminology discussed here will be used throughout the report and a Glossary is included following the References.

Pavement Preservation and Maintenance Terminology

The first set of terms for pavement maintenance terminology that apply to microsurfacing are defined by the FHWA (Geiger 2005) as follows:

- **Pavement preservation** is "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety, and meet motorist expectations."
- **Preventive maintenance** is "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity)."
- **Routine maintenance** "consists of work that is planned and performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service."
- **Corrective maintenance** "activities are performed in response to the development of a deficiency or deficiencies that negatively impact the safe, efficient operations of the facility and future integrity of the pavement section. Corrective maintenance activities are generally reactive, not proactive, and performed to restore a pavement to an acceptable level of service due to unforeseen conditions."

The report will refer to various specific applications of microsurfacing using these terms where appropriate and as a "pavement preservation and maintenance program" when discussing it in general terms.

Microsurfacing Versus Slurry Seal Terminology

The issue of whether or not microsurfacing is merely a polymer-modified slurry seal has yet to be settled. ISSA's *Inspector's Manual for Slurry Systems* (2010a) differentiates each technology in the following manner:

- **Slurry seal**—A mixture of aggregate, emulsified asphalt, water, and additives properly proportioned, mixed, and spread over a properly prepared surface. Slurry seal is applied in a mono-layer. A mono-layer is considered one stone thickness (based on the largest stone in the gradation) spread on the pavement surface.
- **Polymer-modified slurry seal**—A slurry seal designed with an asphalt emulsion that has been modified with a polymer or other special purpose additive to enhance one or more properties of the slurry to better meet a particular project requirement. Modifying emulsions may improve the bond between the asphalt and the aggregate and may improve durability and toughness of the seal.

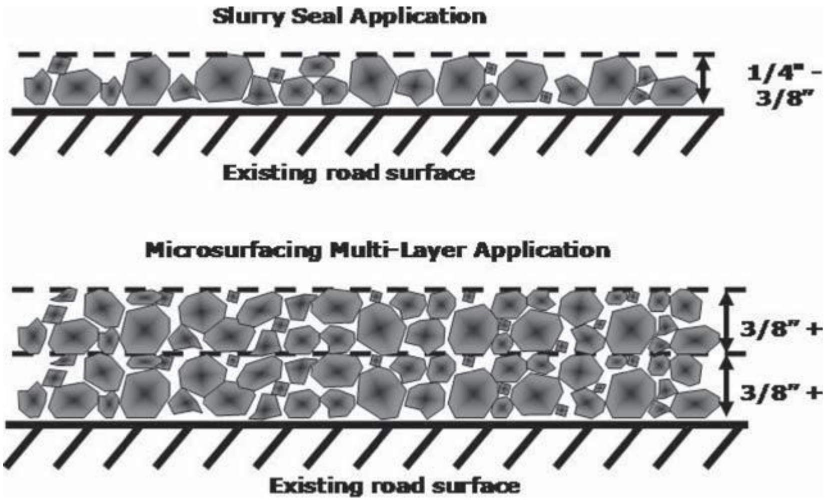


FIGURE 3 Difference between slurry seals and microsurfacing (adapted from Bickford 2008).

- **Microsurfacing**—A mixture of cationic polymer-modified asphalt emulsion, 100% crushed aggregate, water, and other additives properly proportioned and spread over a prepared surface. The special purpose polymers and additives used in microsurfacing allow higher than normal rates of application and multi-layer applications for projects such as rut filling and highway leveling and resurfacing. A multi-layer application allows material depths to exceed the normal one stone thickness rule.

Figure 3 shows the difference between microsurfacing and the two slurry seals and Table 2 consolidates the ISSA definitions and other technical definitions found in the literature. Microsurfacing appears to have three features that differentiate it from slurry seals:

1. It always contains polymers.
2. It cures rapidly through chemical reaction, which permits traffic to be returned in a shorter time.
3. It can be placed in layers thicker than one stone deep.

The California DOT (Caltrans) *Maintenance Technical Advisory Guide* (Caltrans 2009) goes further in its discussion of the differences in the two technologies. Table 3 was taken from that guide and adds additional information to assist the reader in understanding the fundamental differences between microsurfacing and slurry seal. The Asphalt Emulsion Manufacturers Association (AEMA) states that microsurfacing is an alternative to hot mix for rut filling (AEMA n.d.). Finally, a pooled fund study devoted to updating microsurfacing and slurry seal design procedures also faced this terminology issue and concluded that because "constructability issues are the same for both," the two might be categorized as "Slurry Surfacing Systems" (Fugro-BRE/Fugro South 2004). This agrees with the approach used in Australia and New Zealand, where "Slurry Surfacing [is] a general term for Slurry Seal and Microsurfacing" (Austroads 2003b).

With one exception, this synthesis will concentrate the remainder of its discussion strictly on microsurfacing. In chapter three, the topic of project selection will include an analysis of those situations in which microsurfacing is uniquely appropriate and those where a slurry seal is a better option.

PROTOCOL TO DEVELOP CONCLUSIONS, EFFECTIVE PRACTICES, AND FUTURE RESEARCH NEEDS

The major factor in developing a conclusion was the occurrence of similar trends found in two or more research instruments. Additionally, greater weight was given to information developed from the survey of highway agencies. The literature review and specification content analysis were considered to be supporting sources. Finally, the case studies were used to validate the conclusions as appropriate because they are examples of how U.S. and Canadian highway agencies have actually implemented microsurfacing.

Effective practices were identified in the same manner as conclusions, with one exception. An effective practice is specific to a single factor in microsurfacing practice and may only apply to a specific set of circumstances, such as agencies in northern climates; whereas, conclusions can be generalized. Future research needs were developed based on practices that were described in the literature and confirmed as effective by one of the research instruments but generally not widely used. Gaps in the body of knowledge found in this study were also used to define the areas where more research would be valuable.

TABLE 2
CURRENT DEFINITIONS FOR MICROSURFACING AND SLURRY SEAL

Source	Microsurfacing	Slurry Seal
ISSA (2010a)	A mixt ure of *cationic polymer modified asphalt* emulsion, 100% crushed aggregate, water and other additives…*multi-layer applications* for projects such as rut filling…"	"A mixture of aggregate, emulsified asphalt, water, and additives … applied in a *mono-layer*…one stone thickness …"
AEMA (undated)	"…*a polymer modified quick traffic* slurry seal system…can be placed in much *greater thicknesses* than conventional slurry seal…"	"…a blend of emulsion, aggregate, water, and additive."
Hicks et al. (1999)	"… a *polymer-modified cold* slurry system…uses aggregate, which normally passes the 9-mm (3/8-in.) sieve. [It will] *cure and develop strength faster* than conventional slurry seals and can be *placed in thicker layers* …"	"…a *slow- or quick-set emulsion* and aggregates that typically pass the 6-mm (1/4-in.) sieve… used to seal minor surface cracks and voids, retard surface raveling, fill minor ruts, and improve surface friction."
Hicks et al. (2000)	"A mixture of *polymer modified* asphalt emulsion, mineral aggregate, mineral filler, water, and other additives, properly proportioned, mixed, and spread on a paved surface."	"A mixture of *slow setting* emulsified asphalt, well graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of old pavements, to restore a uniform surface texture, to seal the surface to prevent moisture and air intrusion into the pavement, and to provide skid resistance."
FLHD (2003)	"Microsurfacing emulsions *break and cure much more quickly* than unmodified slurry seals, allowing *faster return to traffic* and less traffic damage ... can be placed *in thicker lifts* for rut-filling. By definition, microsurfacing contains polymers… microsurfacing can be thickly applied in multiple layers… [it] breaks chemically…[which] permits the microsurfacing to gain cohesive strength rapidly."	"…slurry seals may or may not contain polymers. Slurry seals are generally laid at thicknesses of 0.40 to 0.60 in. (1 to 1.5 cm), whereas slower breaking slurry seals cure on the surface, "skinning over" and preventing thorough breaking and curing when they are applied at greater thicknesses."
Austroads (2003b)	"A Bituminous Slurry Surfacing, usually containing *polymer,* which is capable of being spread in *variably thick layers* for rut-filling and correction courses, and for wearing course applications requiring good surface texture."	"A thin layer of Bituminous Slurry Surfacing, usually without a polymer modifier."

AEMA = Asphalt Emulsion Manufacturer's Association.

TABLE 3
CALIFORNIA DOT MAINTENANCE TECHNICAL ADVISORY GUIDE ON MICROSURFACING VERSUS SLURRY SEAL

Differences In:	Microsurfacing	Slurry Seal
Asphalt Emulsion	Always polymer modified, quick set	Could be polymer modified
Aggregate Quality/Gradation	Stricter specifications for sand equivalent; use only Type II and Type III	Can use Type I, II, or III
Additives/Break	Chemical break largely independent of weather conditions	Breaking and curing dependent on weather conditions
Mix Stiffness/Equipment	Stiffer mix, use augers in the spreader box and secondary strike-off	Softer mix, use drag box
Applications	Same as slurry seal + rut filling, night work, correction of minor surface profile irregularities	Correct raveling, seal oxidized pavements, restore skid resistance

Source: Caltrans (2009).

ORGANIZATION OF THE REPORT

The information collected in this study will be presented as follows:

- Chapter two—Summary of Information Collected: The research methodology and key characteristics of the agencies that responded to the survey are covered in detail.
- Chapter three—Design Practices: Microsurfacing project selection, material specifications, job mix formula, and other activities related to the development of microsurfacing construction documents are presented.
- Chapter four—Contracting Procedures: Microsurfacing contract types, administration issues, and warranties are addressed in this chapter.
- Chapter five—Construction Practices: The various aspects of microsurfacing construction are reviewed.
- Chapter six—Microsurfacing Equipment Practices: The various components of the microsurfacing equipment train are discussed.
- Chapter seven—Quality Control and Quality Assurance and Performance Measures: This chapter reviews the salient aspects of quality management as well as commonly used metrics to measure microsurfacing performance.
- Chapter eight—Case Studies: Six case studies from five states and one Canadian province are presented, highlighting specific aspects of microsurfacing success at the agency level.
- Chapter nine—Conclusions: This chapter synopsizes the conclusions and effective practices found in the report and makes recommendations for future research to fill gaps in the body of knowledge.

CHAPTER TWO

SUMMARY OF INFORMATION COLLECTED

INTRODUCTION

This report is the result of a comprehensive literature review, a survey of both U.S. and Canadian public highway agencies, a content analysis of DOT microsurfacing specifications, and case studies of DOT-specific experiences with microsurfacing. The resulting information is merely a recitation of information found by each of those instruments and conclusions drawn are based on multiple confirmations from two or more study instruments. It must be noted that the synthesis represents a "snapshot" in time with respect to the state of the practice. Wherever possible, seeming conflicts between survey responses and other information, such as the literature, were verified by a third source. However, when no conflict arose, the information reported in the survey was accepted and carried into the analysis.

SYNTHESIS METHODOLOGY

The synthesis employed the following major study instruments:

1. Comprehensive literature review,
2. Survey of U.S. state and Canadian province transportation agencies,
3. Content analysis of U.S. microsurfacing specifications, and
4. Case study analysis of selected U.S. and Canadian microsurfacing programs.

The structure and content of each of the instruments was developed to integrate with all other instruments, which allows the output of each instrument to be mapped with the output of the others identifying trends in the data.

The survey was issued to the maintenance engineers in 50 U.S. state DOTs and 13 Canadian provincial or territorial MOTs (see Appendix A for details). A survey on microsurfacing practices provided responses from 44 U.S. state DOTs and 12 Canadian provincial MOTs, resulting in an overall response rate of 89%. The survey respondents are shown in Figure 4. This analysis separated the U.S. and Canadian responses to account for the difference in the construction contracting regulatory environment that exists in both countries and also to highlight potential innovative Canadian microsurfacing practices, keeping them from being lost in the total survey population. It can be noted that local agencies at the municipal and county levels are also known to use microsurfacing. However, no effort was made to survey these agencies, as it was beyond the scope of this synthesis. Finally, the reader must understand that because the survey results are presented in tabular form throughout the report that attempting to add up the various responses and get them to sum to the same number for the United States and Canada cannot be done. Many of the questions asked respondents to check all answers that applied. A number of the questions were follow-up questions answered only by those respondents that answered in a prescribed manner on the previous questions and some of the surveys were not totally completed. Therefore, the survey results are reported exactly as they were observed.

Standard microsurfacing specifications from all 50 U.S. states plus the District of Columbia and the FHWA Federal Lands Highway Division (FLHD) were assembled. Of that group, 18 contained sections that specifically contained the word "microsurfacing." The others may have been used for microsurfacing under another term such as "surface treatment" or even "slurry seal." Other section titles found were: "Cold-Laid Latex Modified Emulsion Pavement Course" (Pennsylvania) and "Paver-laid Surface Treatment" (Alabama). An example of the indeterminate state of microsurfacing terminology is the FLHD specification, which states in Section 410—Slurry Seal: "This work consists of applying an *asphalt slurry seal or a polymer modified microsurfacing mix* on an existing pavement surface" (FLHD 2003, italics added). The word "microsurfacing" is found only in this sentence and the remainder of the section does not differentiate between the two treatments, effectively giving both treatments the same specification. As a result of the potential for inaccurate analysis, only the 18 specifications that contained a reference to microsurfacing were included in the content analysis.

A case study analysis was also undertaken to furnish specific information on microsurfacing as experienced by selected agencies. Each case study was selected for a specific focus, which furnishes a unique perspective on an agency's microsurfacing program. Table 4 shows the case studies and the reason each was selected.

GENERAL AGENCY MICROSURFACING INFORMATION

To put the information in this report in proper context, the reader needs to understand the relative magnitude of microsurfacing programs in the United States and Canada. Table 5

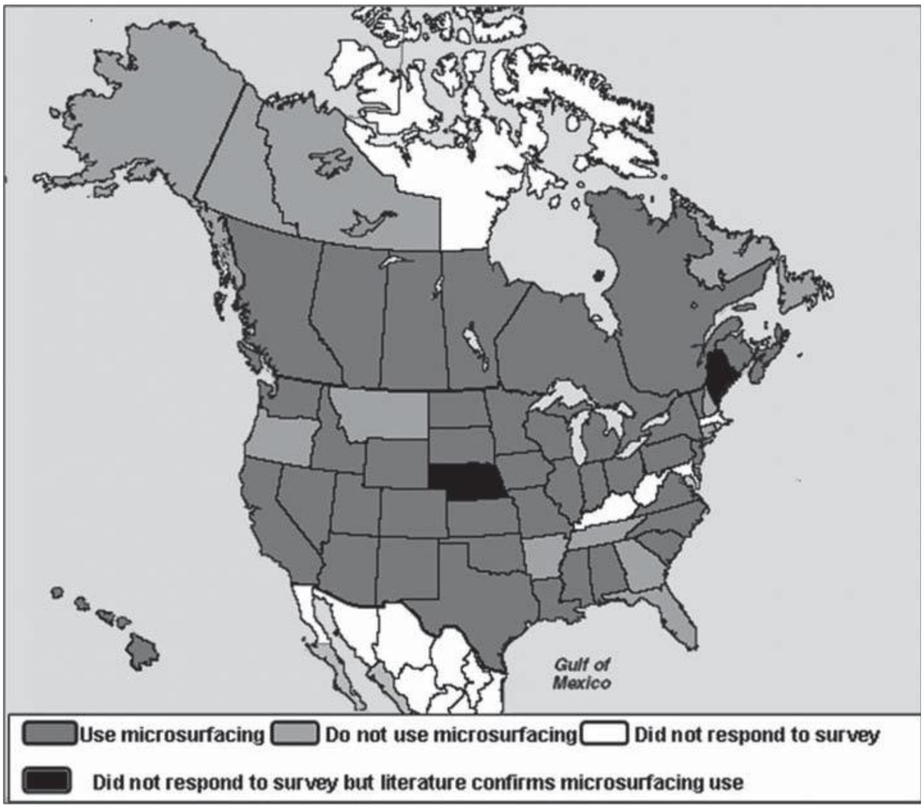


FIGURE 4 Survey responses from U.S. DOTs and Canadian MOTs.

TABLE 4
CASE STUDY SUMMARY

Agency	Reason for Inclusion
Georgia DOT	Agency with successful demonstration project but does not use in program. Also included road noise analysis.
Kansas DOT	Microsurfacing on jointed concrete pavement.
Maine DOT	Agency uses microsurfacing to maintain both roads that are built to DOT standards and roads that are not built to DOT standards.
Minnesota DOT	Agency has robust internal microsurfacing research program, including trials of softer binders to reduce cracking.
Oklahoma DOT	Agency has 9-year field performance monitoring program and an ongoing rigorous field test that focuses on microsurfacing skid resistance and macrotexture.
Ontario MTO	Agency has completed rigorous studies relating microsurfacing to traffic safety.

TABLE 5
SUMMARY OF MICROSURFACING PROGRAM STATISTICS FROM SURVEY RESPONDENTS

Characteristic	U.S. DOT	Canada
Percent of Rural Local Roads with Microsurfacing	2.2%	0.0%
Percent of Rural Interstate Roads with Microsurfacing	5.6%	9.1%
Percent of Urban Local Roads with Microsurfacing	6.0%	0.0%
Percent of Urban Interstate Roads with Microsurfacing	10.7%	0.3%
Percent Total Network with Microsurfacing	3.1%	6.9%
Average Microsurfacing Approximate Annual Volume	$3.0 million	$4.0 million*
High Reported	$12.0 million	$10.0 million*
Low Reported	$0.5 million	$0.06 million*
Average Microsurfacing Annual Program Size	60 miles (96.6 km)	57 miles (92 km)
High Reported	150 miles (241.4 km)	124 miles (200 km)
Low Reported	12 miles (19.3 km)	10 miles (16 km)
Agencies with Microsurfacing Installed by In-house Crews	1	2
Agencies with Microsurfacing Installed by Contractor Crews	30	6

*These are Canadian dollars, which at the time of this writing is trading at roughly par to the U.S. dollar.

summarizes the survey responses from those respondents that indicated that microsurfacing was used in their organizations.

Table 5 shows that microsurfacing constitutes a relatively low percentage of most agencies' programs. Texas ($12 million), Tennessee ($9.3 million), Louisiana ($6.3 million), and North Dakota ($6.3 million) had the largest U.S. microsurfacing programs. In Canada, Saskatchewan ($10 million) and Manitoba ($9 million) led the provinces. The table shows that microsurfacing is largely installed by contract crews. Only one U.S. DOT and two Canadian MOTs have the capability to apply microsurfacing using agency personnel. Minnesota puts approximately 5% of its annual program down with DOT maintenance crews. Quebec and Saskatchewan agency personnel install 2% and 5%, respectively. The study found no specific information as to why microsurfacing constitutes such a small percentage of the typical agency's pavement preservation and maintenance program. However, a check of the bid tabulations for a May 2010 letting by the Utah DOT shows roughly equivalent quantities of microsurfacing and chip seal being bid at $2.07 per square yard and $1.72 per square yard, respectively, roughly a 20% difference in price. Therefore, economics may be the factor, as an agency can preserve 20% more lane-miles of its roads each year by using the lower priced treatment.

Finally, because microsurfacing can be used as a tool in an agency's preventive maintenance program, the survey respondents were asked if they applied it on a regular cycle as well as the length of the cycle if they did. The Indiana and Utah DOTs reply affirmatively and Indiana stated that the preventive maintenance cycle averaged 8 years. Nova Scotia was the only other respondent to reply yes to this question and it reported that it used a 6-year cycle. The written comments on this issue suggest that microsurfacing is viewed primarily as a pavement preservation tool in North America. Several respondents stated that their agencies use it specifically to *extend the underlying pavement's* surface life when asked to estimate microsurfacing service life. Figure 5 summarizes the survey responses. The service life reported by U.S. DOTs averaged 6 years within a

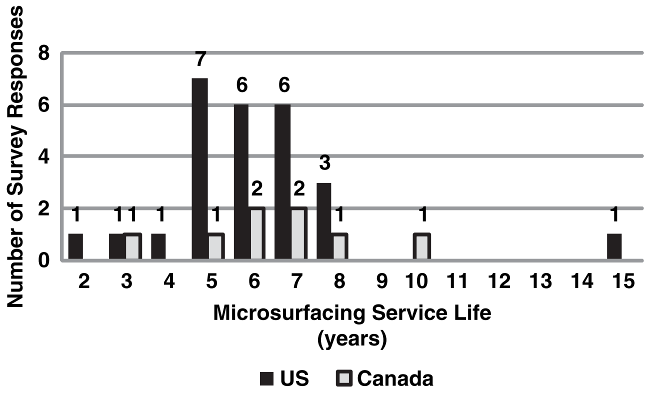


FIGURE 5 Summary of survey microsurfacing service life responses.

range of 1 year to 15 years. Canadians agencies reported an average microsurfacing service life of 7 years, with a low of 3 years and a high of 10 years.

SUMMARY AND CONCLUSIONS

Microsurfacing is an effective tool for pavement preservation and maintenance programs in North America. It is not used in large amounts nor is it a technology that is kept in-house by public highway agencies. Overall, the survey respondents were satisfied with their microsurfacing contractors' performance and depend on the technology to extend pavement service life. The output from the study instruments discussed in this chapter will be used to present a more detailed discussion of the state of the practice in microsurfacing in the following chapters. It will also be used to identify effective practices that can be implemented by both agencies with extensive microsurfacing experience or agencies that are contemplating adding it to their pavement preservation toolbox.

The following conclusion was found in this chapter:

Microsurfacing is fundamentally viewed as a tool to extend the service life of the existing pavement and thus it is used primarily as a pavement preservation treatment.

CHAPTER THREE

DESIGN PRACTICES

INTRODUCTION

First, the survey asked respondents to indicate if they used a formal design and, if so, which one. The U.S. sample contained 31 responses, of which 12 reported using a single formal design method and 3 indicated that they had used 2 different methods in the past 5 years. The results regarding the survey are as follows:

1. ISSA Design Method for Microsurfacing (2010b): ISSA A143—12 responses.
2. ASTM Design Method for Slurry Seals (ASTM 2007a): ASTM D 3910-98—3 responses.
3. ASTM Design Method for Microsurfacing (ASTM 2007b): ASTM D 6372-99a—2 responses.
4. Texas Transportation Institute Design Method for Microsurfacing (West et al. 1996): TTI 1289—1 response.

Additionally, 11 responses noted the use of empirical methods based on an agency's past experience, and 4 agencies claimed to use no formal method. The Canadian sample was similar; 4 of 8 respondents reported using the ISSA A143 method (2010b) to design their microsurfacing and 4 use an empirical method.

Microsurfacing design is essentially a six-step process:

1. Identifying and characterizing the roads where a microsurfacing treatment is appropriate.
2. Selecting materials: emulsion, aggregate, mineral filler, additives, and water.
3. Developing a job mix formula.
4. Laboratory testing of the job mix formula [also referred to as the "mix design" by some authors such as ISSA (2010b)].
5. Developing application rates.
6. Preparing construction documents based steps 1–5.

ISSA stresses the importance of the design process in its most recent technical publication:

> Mix designs must be completed by a competent laboratory that is experienced with state of the art asphalt emulsion/aggregate mixing technology as it applies to slurry systems. The laboratory must possess the necessary specialized equipment and knowledgeable staff to perform the required tests. Knowing the specific system and the relationships of all the components is critical to the development of a good mix design. Each of the material components, aggregate, asphalt emulsion, water, and additives, must meet all job specifications and test requirements. Individual materials must be qualified through testing before the laboratory will perform further tests to determine the mix compatibility and performance under simulated wear conditions (ISSA 2010b).

The job mix formula development process seeks to determine the quality of the materials and evaluate how they will interact with each other during and after treatment curing. The job mix formula procedure includes the various phases of the microsurfacing process in which the following questions are answered for each phase:

- Mixing: Will the components mix together and form true, free-flowing microsurfacing?
- Breaking and Curing: Will the emulsion break in a controlled way on the aggregate, coat the aggregate, and form good films on the aggregate? Will the emulsion build up cohesion to a level that will resist abrasion owing to traffic?
- Performance: Will the microsurfacing resist traffic-induced stresses? (National Highway Institute 2007).

The process involves prescreening the possible alternatives for materials, the job mix formula itself, and final testing. At every step, the laboratory addresses mixing, breaking, curing, and performance issues to ensure that the final design is optimized both for the actual materials and for the environment in which the microsurfacing will be installed. Table 6 is a summary of survey responses to the question: Which entity is responsible for performing the microsurfacing design? The table shows that only 7 agencies do their own job mix formula, whereas 22 U.S. and 6 Canadian agencies delegate this responsibility to the microsurfacing contractor through the construction contract. Additionally, of the agencies that out-source the job mix formula, only two U.S. and two Canadian agencies do not require that the final job mix formula be reviewed by an agency representative.

That the majority of the respondents that use microsurfacing (77%) chose to give the contractor the responsibility for the job mix formula leads to the conclusion that microsurfacing projects are being delivered as *de facto* performance contracts. The Canadian respondents indicated that all Canadian road agencies require a warranty that ranges from 1 to 2 years. In the United States, seven agencies reported requiring a warranty on their microsurfacing projects. The details of the warranties are shown in Table 7.

TABLE 6
JOB MIX FORMULA DEVELOPMENT RESPONSIBILITY SUMMARY

Entity That Develops the Job Mix Formula	Number of Responses	
	U.S. (of 28)	Canada (of 8)
Agency in-house design section	2	1
Agency in-house maintenance group	2	0
Agency in-house materials lab section	1	1
Microsurfacing contractor under the construction contract	21	6
Independent lab for the microsurfacing contractor under the construction contract	1	0
Do not know	1	0

Finally, when asked to rate how they perceived the performance of their microsurfacing program (Table 8), the majority of the agencies rated their microsurfacing performance as "Good" or "Excellent" and none rated it as one of the unsatisfactory ratings ("Poor" or "Very Poor"). Taking the results of Tables 6, 7, and 8 leads to the following effective practice:

Microsurfacing design can be successfully assigned to the microsurfacing contractor with the agency reviewing and/or approving the final job mix formula.

However, applying the perfectly designed job mix to a road that will not benefit from microsurfacing is a formula for failure. Therefore, "project selection play[s] a key factor in overall success of microsurfacing" (Wood and Geib 2001).

PROJECT PLANNING AND ROAD SELECTION

The mantra of the pavement preservation movement in the United States is "the right treatment, on the right road, at the right time" (Galehouse et al. 2003). As such, project selection becomes the key to a successful microsurfacing program. Moulthrop (2007) emphasizes Wood and Geib's (2001) finding when he states: "Failures are generally a result of poor project selection—there is a need to educate users on the proper use of slurry and microsurfacing." Table 9 is a summary of the project selection criteria found in the literature. Its format came from the most detailed source (Caltrans 2009). As noted in chapter one, it shows the cited project selection criteria for both treatments in those sources where both were given.

Analysis of Table 9 shows that microsurfacing is the appropriate option in most of the categories where its utility

TABLE 7
MICROSURFACING WARRANTY SUMMARY

Agency	Microsurfacing Warranty Length	Warranty Criteria
Louisiana	1 year	Standard construction warranty for surface defects
New Hampshire	1 year	Surface defects
New York	1 year	Raveling, flushing, delamination, snowplow damage
Oklahoma	1 year	Standard construction warranty for surface defects
Alberta	1 year	Raveling
British Columbia	1 year	Standard construction warranty for surface defects
Quebec	1 year	Standard construction warranty for surface defects
Saskatchewan	1 year	Standard construction warranty for surface defects
Nevada	2 years	Standard construction warranty for surface defects
Texas	2 years	Raveling, flushing
Manitoba	2 years	Raveling, friction
New Brunswick	2 years	Standard construction warranty for surface defects
Nova Scotia	2 years	Standard construction warranty for surface defects
Ontario	2 years	Raveling, flushing
Indiana	3 years	Raveling, friction, rutting

TABLE 8
MICROSURFACING PERFORMANCE RATINGS

Performance Rating	Excellent	Good	Fair	Poor	Very Poor
U.S.	1	20	4	0	0
Canada	1	7	0	0	0
Total	2	27	4	0	0

TABLE 9
PROJECT PLANNING AND SELECTION CRITERIA SUMMARY

G =Good; F = Fair; P = Poor; N = Not			Pavement Condition									Parameters								Desired Benefits				
M = Microsurfacing (general); MII = Microsurfacing (Type II); MIII = Microsurfacing (Type III); S = Slurry Seal			Surface Condition				Rutting		Cracking			Traffic Volumes			Maintenance issues			Type						
Source	Reference	Type	Friction	Raveling	Oxidation	Bleeding	< 1/2"	>1/2"	Alligator	Longitudinal	Transverse	ADT<3K	ADT = 3K to 5K	ADT >5K	Cool Temps	Stopping Points	Snow plow use	Urban	Rural	Early Opening to Traffic	Multiple Lifts Needed	Night-time Work	Minimize User Delay Costs	Expected service life
Caltrans	Hicks et al 2000	MII	-	F	G	N	G	N	N	N	N	G	G	G	F	G	F	G	G	G	G	F	G	3 TO 4
		MIII	-	G	G	N	G	G	P	N	N	G	G	G	F	G	F	G	G	N	N	F	F	3 TO 4
Ohio DOT	Hicks et al 2000	M	G	G	G	-	G	G	N	N	N	G	G	-	-	-	-	-	-	-	-	-	-	3 TO 8
Oregon DOT	Hunt 1991	S	-	G	G	-	N	N	P	N	N	-	-	-	-	-	-	-	-	-	-	-	-	-
Asphalt Inst	AI 1983	S	-	G	-	-	-	-	F	P	P	-	-	-	-	-	-	-	-	-	-	-	-	-
Iowa DOT	Jahren et al 1999	M	G	G	-	G	G	G	N	N	N	G	G	G	-	-	G	-	-			-		-
		S	F	G	-	G	G	G	N	N	N	G	P	N	-	-	F	-	-			-		-
Wisconsin DOT	Shober 1997	M	G	G	G	G	G	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2 TO 6
New York State DOT	NYSDOT 1999	M	-	F	-	-	G	G	P	P	P	G	G	G	-	-	-	-	-	-	-	-	-	-
		S	-	P	-	-	P	P	P	P	P	G	N	N	-	-	-	-	-	-	-	-	-	-
USACE	ASTM 1998	M	G	G	G	-	F	F	P	F	F	-	-	-	-	-	-	-	-	-	-	-	-	-
		S	G	F	F	-	-	-	P	P	P	-	-	-	-	-	-	-	-	-	-	-	-	-
Asphalt Contractor	Mouthrop et al 1999	M	G	G	G	G	G	G	F	G	G	G	G	G	-	-	G	G	G	G	G	-	G	-
		S	G	G	N	G	F	N	N	P	F	G	G	G	-	-	G	G	N	N	N	-	N	-
FHWA	FHWA 2007	MII	-	G	G	G	G	G	N	N	N	G	G	G	G	G	-	-	-	-	-	G	-	7 TO 10
		MIII	-	G	G	G	G	G	N	N	N	N	G	G	G	G	-	-	-	-	-	G	-	7 TO 10
FLHD	FLHD 2009	M	-	-	-	-	G	G	-	-	-	G	G	G	G	-	-	G	G	G	G	G	G	-
		S	-	-	-	-	N	N	-	-	-	G	N	N	-	-	-	N	G	N	N	-	-	-
Austroads	Austroads 2003	M	G	-	-	-	G	G	P	P	P	G	G	G	-	-	-	F	G	G	G	-	G	-
		S	F	-	-	-	F	N	N	N	N	F	N	N	-	-	-	G	N	-	-	-	-	-
Indiana DOT	Labi et al 2007	M	-	G	G	G	G	G	F	F	F	G	G	F	-	-	-	G	F			-		5 TO 6
Texas DOT	Smith and Beatty 1999	M	G	-	G	F	G	G	F	F	F	G	G	G	-	G	-	G	G	G	G	-	-	7 TO 10
Caltrans	Olsen 2008	M	G	-	G	G	G	G	F	F	F	G	G	G	G	G	-	G	G	G	G	G	G	5 TO 7
		S	G	-	F	F	-	-	P	P	P	G	G	G	N	-	-	G	-	N	N	N	P	5 TO 7
Iowa DOT	Jahren & Behling 2004	M	G	F	G	G	G	G	F	P	P	-	-	-	-	-	P	-	-	-	-	-	-	-

AI = Asphalt Institute.

was rated. However, it was not recommended by the majority of the authors in the literature for addressing cracking issues. This leads to the idea that microsurfacing will only perform properly when applied to structurally sound pavements. Additionally, its operational benefits support its use in pavement preservation programs. Microsurfacing's ability to accept traffic within 1 h of installation (Johnson et al. 2007) not only reduces life-cycle costs by minimizing user-delay costs but it also enhances work zone safety by minimizing the time workers are exposed to active traffic. That the literature shows its use on all types of roads with no limitation on traffic volume accentuates its value for high-volume urban freeway preservation projects. This is reinforced by research that proved it performs well on both asphalt and concrete pavements (Moulthrop et al. 1996; Wood and Geib 2001). Thus, this analysis leads to the conclusion that microsurfacing is a pavement preservation and maintenance tool with very few technical or operational limitations.

Table 10 consolidates the recommendations in each of the categories. "Sum 1" is the number of observations where it was rated either "good" or "fair." "Sum 2" is the number of observations where it was rated either "poor" or "not recommended." "Net" is Sum 1 minus Sum 2. Thus, a positive number would indicate that microsurfacing would generally be recommended for those categories and a negative number would argue against its use. The table shows that microsurfacing is expected to perform well to treat pavement distresses in the following in order:

1. Rutting—16 for shallow ruts; 14 for deeper ruts
2. Raveling—12
3. Oxidation—12
4. Bleeding—7

It can also be used to correct a loss of pavement friction (net 9). However, based on the net, it shows that microsurfacing has limited ability to address most cracking issues as it was given a negative rating more times than it was rated positive. Microsurfacing is also shown to be viable for all levels of traffic as well as useful in both urban and rural settings. Finally, it appears to be robust enough to be effectively used in locations where the work has to be done at night or in cool weather, as well as where stresses resulting from stopping and snow plowing are present. This analysis is validated by a study of microsurfacing performance. "Microsurfacing generally *will not be effective* if it is applied to pavements that have *working cracks,* that are *structurally inadequate,* or that have *unstable pavement layer materials.* Microsurfacing applied to pavements in the appropriate condition provides seven or more years of service" (Smith and Beatty 1999, italics added). Thus, the mantra cited in the opening sentence of this section is found to be very correct for using microsurfacing as a pavement preservation tool and leads to the following effective practice:

> *Project selection is critical to microsurfacing success and those agencies that only apply microsurfacing to structurally sound pavements are generally satisfied with its performance.*

CANDIDATE ROAD CHARACTERIZATION

Each public highway agency has its own method of assembling a list of roads that need some form of preservation or maintenance to either restore their serviceability or to extend their service life. Thus, the selection of appropriate candidates for microsurfacing cannot be done in a vacuum. The process necessitates that those candidates be evaluated as a group and

TABLE 10
QUANTIFIED OUTPUT FOR MICROSURFACING ONLY FROM TABLE 9

	Pavement Condition				Rutting		Cracking			Traffic Volumes			Maintenance Issues			Type		Desired Benefits			
Recommendation	Friction	Raveling	Oxidation	Bleeding	< 1/2"	>1/2"	Alligator	Longitudinal	Transverse	ADT<3K	ADT = 3K to 5K	ADT >5K	Cool Temps	Stopping Points	Snow plow use	Urban	Rural	Early Opening to Traffic	Multiple Lifts Needed	Night-time Work	Minimize User Delay Costs
Good	9	9	12	8	15	14	0	1	1	12	13	11	4	6	2	7	7	6	6	4	5
Fair	0	3	0	1	1	1	5	4	4	0	0	1	2	0	2	1	1	0	0	2	1
Sum1	9	12	12	9	16	15	5	5	5	12	13	12	6	6	4	8	8	6	6	6	6
Poor	0	0	0	0	0	0	4	3	3	0	0	0	0	0	1	0	0	0	0	0	0
Not	0	0	0	2	0	1	5	6	6	1	0	0	0	0	0	0	0	1	1	0	0
Sum2	0	0	0	2	0	1	9	9	9	1	0	0	0	0	1	0	0	1	1	0	0
Net	9	12	12	7	16	14	-4	-4	-4	11	13	12	6	6	3	8	8	5	5	6	6

TABLE 11
SURVEY RESPONSES FOR MICROSURFACING SELECTION LOGIC

Reason for Selecting Microsurfacing	Number of Responses		Reason for Selecting Microsurfacing	Number of Responses	
	U.S.	Canada		U.S.	Canada
Provide a Surface Wearing Course	9	0	Fill Surface Rutting	2	4
Prevent Water Infiltration	6	1	Improve Striping Visibility	0	0
Oxidation	3	1	Distress (cracking)	1	0
Raveling	3	2	Improve Friction (skid) Resistance	1	0

each road assigned the appropriate treatment based on its condition and the physical and financial environment in which the treatment will be applied. Many factors are considered. First, the following parameters are normally used to pair roads with appropriate treatments:

- Existing pavement type and age;
- Traffic volume;
- Type, severity, and extent of distress;
- Surface friction;
- Expected service life of the treatment; and.
- Program for the next major rehabilitation or reconstruction.

Once an appropriate treatment is selected, the environment in which it will be constructed is then accounted for and treatment decisions adjusted accordingly (Hicks et al. 2000). These factors include:

- Time of year in which the treatment will be placed.
- Climatic conditions, such as humidity, wind, temperatures, etc.
- Cost of the treatment and availability of funds.
- Availability of qualified contractors.
- Availability of quality materials.
- Pavement noise requirements after application.
- Impact on traffic flow and disruption during construction.

The survey asked respondents to name the reasons they chose microsurfacing in their programs. Table 11 shows the possible responses and the number of times each was cited by U.S. and Canadian respondents. It shows an interesting divergence of practice in the two countries. The U.S. agencies favor microsurfacing to furnish a surface wearing course and to seal the surface from water infiltration, whereas the Canadians use microsurfacing primarily as a rut filler. The U.S. results contradict the analysis shown in Table 10. This indicates that the practice is not reflective of the literature and might show a misunderstanding with regard to the technique's effectiveness in filling ruts. The literature reviewed in Table 9 cites the ability to be installed in multiple layers as one of microsurfacing's desired qualities. Rut filling will generally consist of a rut filling course followed by a full lane-width surface course. Therefore, it is one of the few pavement preservation and maintenance treatments that can restore the transverse geometry of a rutted road. This leads to the conclusion that U.S. agencies are not maximizing the potential benefits of microsurfacing when they do not see it as the primary tool to fill ruts as their Canadian counterparts do.

Table 12 reports the responses of the agencies when asked to indicate what factors were used to characterize the existing substrate as part of their design process. Texas was the U.S. "other" response and it uses a combination of the distress score and ride score developed in its pavement management information system to provide input to the Texas Transportation Institute design method. Ontario was the Canadian "other" response and it uses the pavement condition index in its pavement management information system in design. One can see in the table that qualitative characterization is the dominant design factor followed by roughness.

Table 12 also contains the responses regarding the differences in the design process for urban versus rural roads.

TABLE 12
SURVEY RESPONSES FOR FACTORS USED IN DESIGN

Design Characterization Factor	U.S.	Canada
Qualitative (visual) factors	17	6
Roughness	9	3
Level of oxidation	5	0
Rutting	2	3
Other	1	1
Do not characterize existing conditions in the design process	4	0
Do you vary design based on urban vs. rural? Yes	7	1
No	15	7
Do not know	6	0
If yes, what factors are used? AADT	4	1
Number of ESALs	2	0
Proximity to urban areas	2	0
Proximity to rural areas	1	0

ESAL = equivalent single axle load.

Because the majority of respondents do not differentiate in their design and because many reported using microsurfacing to extend the life of the underlying pavement, there appears to be no need to differentiate between urban and rural microsurfacing design.

Decision Tools

A Foundation for Pavement Preservation study developed a decision tree-based framework with which to select an appropriate surface treatment (Hicks et al. 2000). The project covered most pavement preservation and maintenance treatments used on asphalt pavements including microsurfacing. The study furnishes an example that illustrates a rigorous methodology to ensure that microsurfacing is indeed the appropriate treatment for a given road. A number of U.S. and Canadian agencies have followed suit and developed decision tools to assist maintenance engineers in pairing a pavement distress condition with an appropriate pavement preservation and maintenance treatment (Helali et al. 1996; Nebraska Department of Roads 2004; Li et al. 2006; Berg et al. 2009). Hicks et al. demonstrated how the pavement engineer can optimize the treatments with the distresses with which they are most effective. Figures 6 and 7 are conceptual decision trees for asphalt and concrete pavement preservation and maintenance treatment selection. They were created by synthesizing microsurfacing decision trees found in the literature and they are not meant to be comprehensive but rather are illustrative of the process of selecting a road whose distresses can be adequately addressed by microsurfacing. Figure 6 shows the details of the microsurfacing decision process for raveling as found in Helali et al. (1996), and rutting, a combination of Hicks et al. (1997) and Caltrans (2009).

The decision tree for raveling comes from a Canadian study that was implemented by the Ministry of Transportation (MTO) in Ontario. It provides a clear example that microsurfacing is not an appropriate treatment for asphalt pavements with structural distresses (Helali et al. 1996). The same can be said for the rutting decision tree that springs from research conducted for Caltrans (Hicks et al. 1997; Caltrans 2009). The concrete pavement friction loss tree in Figure 7 is used by the Utah DOT. It shows that when friction loss is localized that mechanical retexturing using shotblasting or diamond grinding will be more cost-effective than microsurfacing. However, as the magnitude of the unsafe area increases, microsurfacing becomes the preferred option based on a lower production cost and reduced user-delay costs (Berg et al. 2009). Finally, the rutting decision tree shows that microsurfacing can be used to correct rutting problems in both pavement types.

Comparing Figures 6 and 7 with the output shown in Tables 9 and 10 confirms the conclusions drawn from that analysis. It also confirms a trend in two different sources of information and leads to identification of the following effective practice:

> *Microsurfacing performs best when applied to correct surface friction, oxidation, raveling, and/or rutting on pavements that have adequate structural capacity.*

Friction Restoration

The review of the literature found two other factors that could influence the decision to use microsurfacing on a given road. The first involved the use of microsurfacing to restore surface friction on an interim basis to quickly react to potential safety hazards found in the course of routine skid testing (Yager 2000). The second was the relative impact of microsurfacing on the environment (Uhlman 2010). Table 13 summarizes the survey results for both issues. The survey question that

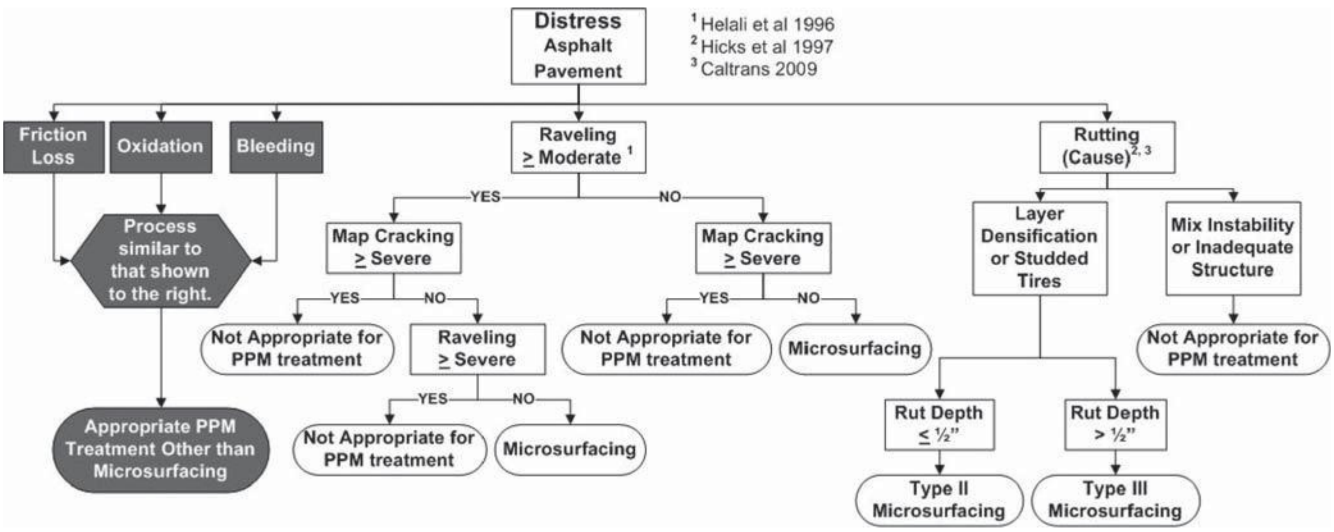


FIGURE 6 Conceptual decision tree for asphalt pavement preservation and maintenance treatment selection (adapted from Helali et al. 1996; Hicks et al. 2000; Caltrans 2009).

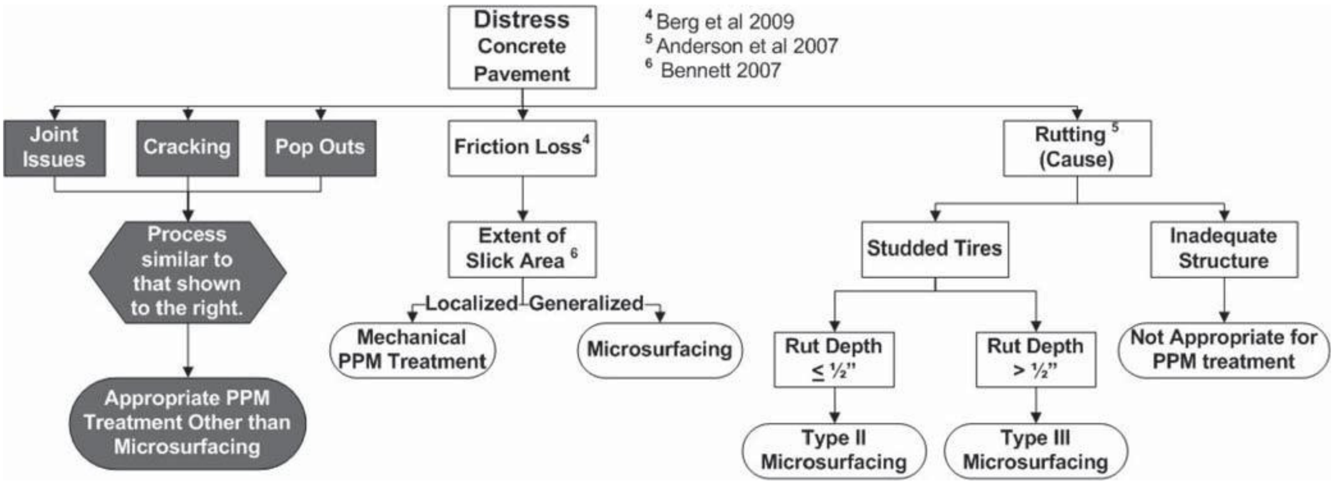


FIGURE 7 Conceptual decision tree for concrete pavement preservation and maintenance treatment selection (adapted from Berg et al. 2009; Anderson et al. 2007; Bennett 2007).

resulted from the first issue sought to determine the use of skid resistance as a metric to characterize candidate roads. The relative ambivalence of the responses in the survey (i.e., 87% either do not consider skid numbers or they vary) clearly demonstrates that microsurfacing projects are rarely selected on a basis of skid numbers alone.

The skid resistance of a pavement is the result of a "complex interplay between two principal frictional force components—adhesion and hysteresis" (Hall 2006). There are other components such as tire shear, but they are not nearly as significant as the adhesion and hysteresis force components. Figure 8 shows these forces and one can see that the force of friction (F) can be modeled as the sum of the friction forces owing to adhesion (F_A) and hysteresis (F_H) per Equation 1 here:

$$F = F_A + F_H \tag{1}$$

From Figure 8 one can see that the frictional force of adhesion is "proportional to the real area of adhesion between the tire and surface asperities," which makes it a function of pavement microtexture. The hysteresis force is "generated within the deflecting and visco-elastic tire tread material, and is a function of speed," making it primarily related to pavement macrotexture (Hall 2006). Thus, if an engineer wants to improve pavement skid resistance through increasing the inherent friction of the physical properties of the pavement that engineer needs to improve both surface microtexture and macrotexture (Davis 1999). Microsurfacing does both.

Figure 9 was developed from data collected for an on-going pavement preservation research project that includes a microsurfacing field test section (Riemer et al. 2010). It shows the pre-microsurfacing baseline measurement for microtexture, measured by a treaded tire skid number, and macrotexture, measured using the sand circle test. Once the microsurfacing was applied, both values show a marked increase and as time goes on they start to deteriorate. The observations in the graph correlate to quarterly measurements and both values appear to be leveling off after two years of service. This research demonstrates the potential for microsurfacing to quickly and effectively enhance the surface friction of a structurally sound pavement that has become unsafe owing to polishing of its aggregate or the loss of macrotexture resulting from flushing or bleeding.

The FHWA issued a technical advisory on pavement friction management (FHWA 2010b) that requires agencies to use the measurements shown in Figure 9 that states: "Because all friction test methods can be insensitive to macrotexture under specific circumstances, it is recommended that friction testing be complemented by macrotexture measurement." Therefore, microsurfacing is shown in Figure 9 to satisfy both components of the FHWA technical advisory and can be used to

TABLE 13
SKID NUMBER AND ENVIRONMENTAL CONSIDERATION SUMMARY

Nation	SN > Agency Minimums	SN< Agency Minimums	SN at or Close to Agency Minimums	SN Vary	SN Not Used in This Context	Consider Environmental Impact	Do Not Consider Environmental Impact
U.S.	2	2	1	10	13	3	25
Canada	0	0	0	2	6	2	6
Total	2	2	1	13	19	5	31

SN = skid number.

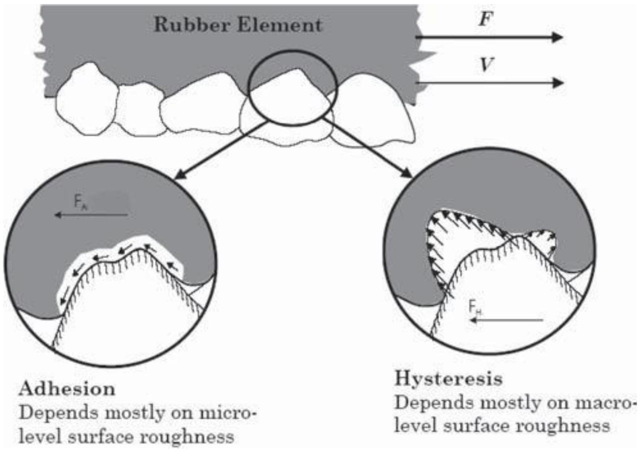


FIGURE 8 Pavement friction model (Hall 2006).

restore pavement friction if an unsafe level of polishing occurs in the pavement surface.

Environmental Aspects of Microsurfacing

Considering environmental impact when choosing pavement preservation and maintenance treatments appears to be rare based on the results shown in Table 13, with only 5 of 36 respondents indicating that it was part of their process. On this issue the literature was markedly divided into two camps. One side advocated the use of bituminous surface treatments as pavement preservation tools and opined that because the consumption of raw materials and energy by microsurfacing was decidedly less than that of a hot-mix asphalt overlay that the treatment inherently had less impact on the environment (Takamura et al. 2001; Uhlman 2010). The other side argued that the use of any kind of petroleum product had a deleterious impact on the environment (Gillies 2006). Table 14 was extracted from a 2010 study by Chehovits and Galehouse that quantified energy use and greenhouse gas emissions of the full suite of FHWA-approved pavement preservation treatments. It shows that there is a huge difference in microsurfacing's environmental impact when compared with a 2-in. hot-mix asphalt overlay. The last column shows that when the savings are annualized to account for microsurfacing's shorter service life that the savings remain large. These numbers do not account for the greenhouse gas emissions from vehicles being delayed in work zones. If those were added, microsurfacing's ability to return the road to full-speed traffic in one hour would overwhelm the typical 8 to 12 h it takes to mill and install an overlay.

The information in Table 14 agrees with findings from an earlier study by Takamura et al. (2001). Figure 10 illustrates the output from that study and provides greater detail with respect to the greenhouse gas emissions, as well as information on raw material consumption. Both studies merely constructed a simplified snapshot of the comparative environmental impact of microsurfacing. Neither included the impact of work zone delays nor the life safety benefits accrued from microsurfacing owing to its ability to minimize the duration of work zone delays and increased congestion during pavement maintenance operations.

The previous discussion and the survey show that the environmental impact of pavement maintenance or preservation projects has yet to be adequately evaluated (Takamura et al. 2001). The survey results (Table 13) that show that the majority of knowledgeable maintenance practitioners do not consider environmental impact in their project development process validates this conclusion and points to the need for future research in the area of sustainable maintenance practices.

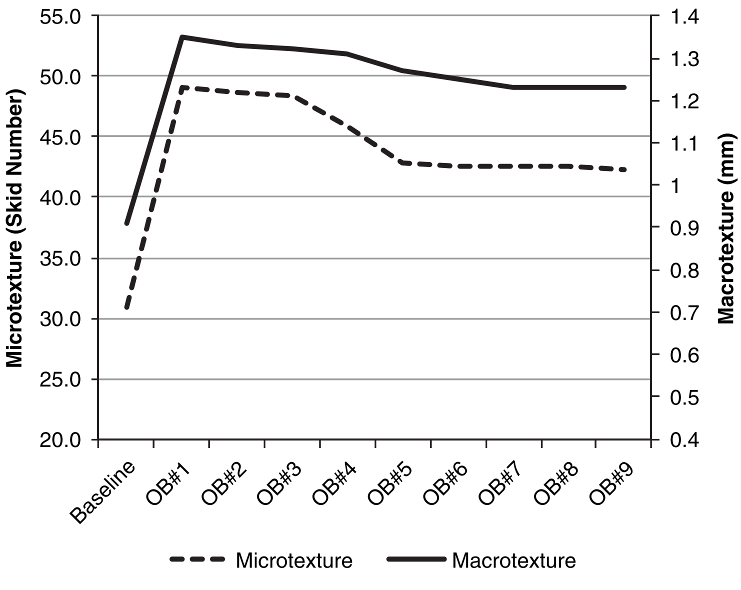


FIGURE 9 Microsurfacing change in skid number and macrotexture over time (Riemer et al. 2010).

TABLE 14
ENVIRONMENTAL IMPACT COMPARISON OF MICROSURFACING VERSUS HOT MIX ASPHALT OVERLAY

<table>
<tr><th rowspan="2">Treatment</th><th rowspan="2">Composition</th><th colspan="2">Energy Use</th><th colspan="2">Greenhouse Gas Emissions</th><th rowspan="2">Life Extension</th><th colspan="2" rowspan="2">Annualized Percent Savings vs. 2-in. Hot-Mix Overlay</th></tr>
<tr><th>BTU/CY</th><th>MJ/CM</th><th>Lbs/SY</th><th>Kg/SM</th></tr>
<tr><td rowspan="2">Hot-Mix Asphalt Overlay</td><td>1.5 in. (3.8 cm)</td><td>46,300</td><td>59</td><td>9.0</td><td>4.9</td><td>5–10 yr</td><td rowspan="2">Energy Use Savings</td><td rowspan="2">Greenhouse Gas Savings</td></tr>
<tr><td>2.0 in. (5.0 cm)</td><td>61,500</td><td>77</td><td>12.3</td><td>6.7</td><td>5–10 yr</td></tr>
<tr><td rowspan="2">Micro-surfacing</td><td>Type III</td><td>5,130</td><td>6.5</td><td>0.6</td><td>0.3</td><td>3–5 yr</td><td>83%–86%</td><td>90%–92%</td></tr>
<tr><td>Type II</td><td>3,870</td><td>4.9</td><td>0.4</td><td>0.2</td><td>2–4 yr</td><td>83%–84%</td><td>91%–92%</td></tr>
</table>

Adapted from Chehovits and Galehouse (2010).

This conclusion is especially valid given the current widespread focus on sustainable design and construction practices (Takamura et al. 2001; Uhlman 2010). The crux of sustainable engineering practices revolves around judicious selection of materials, which is the subject of the next section.

SELECTION OF MATERIALS

Once a road has been identified as a microsurfacing project, the next step is to select the appropriate materials. The components of a microsurfacing job mix consist of emulsion, aggregate, mineral filler, additives, and water. It is important that each of these ingredients be compatible with each other for the microsurfacing to work as designed. Therefore, the mix design process is necessarily based on laboratory results, which are in turn used to optimize the job mix formula.

Emulsion

"Asphalt emulsions are dispersions of asphalt in water stabilized by a chemical system" (National Highway Institute 2007). They are manufactured by blending emulsifying agents with the base asphalt to permit it to disperse uniformly, creating a temporary mixture. This mixture "breaks" upon placement and releases the water leaving behind the asphalt (called residual asphalt) (Caltrans 2009). Cationic emulsions are typically used in microsurfacing. The literature cites CSS-1h (cationic–slow setting–low viscosity–hard; see the Glossary for abbreviations of emulsion types) as the most common (Moulthrop et al. 1999). Some agencies prefer quick setting emulsions such as CQS-1h to reduce the amount of traffic disruption and delay (ISSA 2010a).

Emulsions can also be specially formulated to ensure compatibility with local aggregates and to meet appropriate mix design parameters. The survey asked respondents to indicate which type of emulsions were commonly used in their microsurfacing program and the content analysis of the microsurfacing specifications also sampled for that information. The results are shown in Table 15 (note the table only lists binders that were cited by survey respondents). A trend in the data was found that showed that only 3 of 28 U.S. agencies used more than a single emulsion type. All of the specifications contained only a single emulsion, which was also true for the Canadian agencies. The use of a single microsurfacing binder coupled with the reported microsurfacing performance results in Table 8 (i.e., 100% of the agencies rated their microsurfacing performance as "Fair," "Good," or "Excellent") indicates that an agency can select a single binder that works best for its specific climatic and traffic environment and use it exclusively in their microsurfacing program. Agency satis-

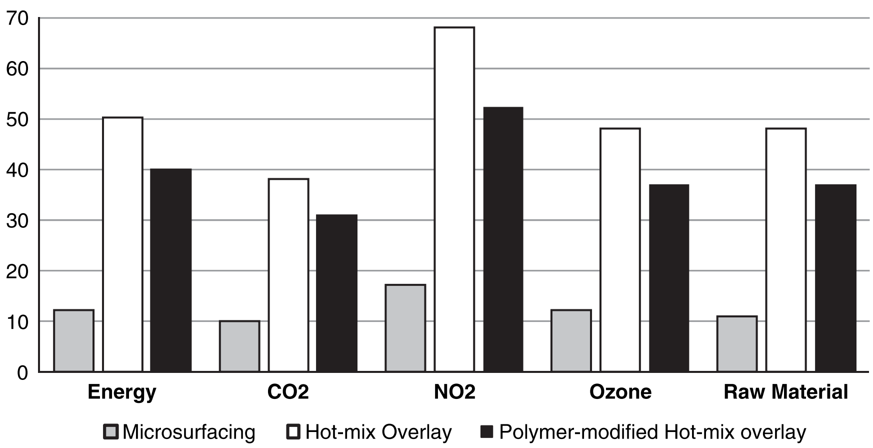


FIGURE 10 Comparative environmental impacts of three pavement preservation and maintenance treatments (adapted using data taken from Takamura et al. 2001).

TABLE 15
MICROSURFACING BINDER USAGE SUMMARY FROM SURVEY AND CONTENT ANALYSIS

Nation	CSS-1P	CSS-1h*	CSS-1hP	CQS-1h*	CQS-1hP	Ralumac™	Quick Set Mixing Grade	CRS-1P	CRS-2P
U.S.	1	6	7	5	5	2	1	1	1
Canada	3	2	1	0	2	0	0	0	0
Total	4	8	8	5	7	2	1	1	1
Content Analysis Totals	2	9	4	1	4	0	0	0	0

*Note all the specifications that called for CSS-1h and QS-1h also specified that it be polymer or latex modified.
See Glossary and Abbreviations for emulsion grade abbreviations.

faction with the performance of a single binder can be identified as the following effective practice:

Microsurfacing programs implemented with a single binder type can yield satisfactory performance in a given agency's climate and traffic conditions.

Microsurfacing emulsion specifications are similar standard emulsion specifications and contain requirements for physical characteristics such as stability, binder content, and viscosity. Polymers are added to microsurfacing emulsions to reduce thermal susceptibility and promote aggregate retention after curing and opening to traffic (ISSA 2010a). Additionally, polymers improve the binder's softening point and its flexibility, which translates to better thermal crack resistance. However, there is a low effective limit to the amount of reflective cracking microsurfacing will resist. Finally, the polymers permit microsurfacing to be placed in thicker sections of two to three stones thick, which enables its use in rut filling.

Emulsions are usually modified with latex in an emulsion of polymer particles. The asphalt and latex do not combine. The latex and the asphalt particles intermingle to form an integrated structure as shown in Figure 11 (note the aggregate particles contained in a microsurfacing mixture are not shown in this figure. Figure 11 depicts only the interaction of the latex with the asphalt in the microsurfacing mixture). Microsurfacing emulsion is modified with either natural latex or styrene butadiene styrene latex. It is possible for the latex to separate from the emulsion owing to the differences in density. To correct this, the latex is remixed by circulating it and the emulsion in the tanker before it is transferred to the microsurfacing machine for installation (ISSA 2010a). The survey had 23 responses citing polymer use, 7 citing natural latex, and 2 styrene butadiene styrene.

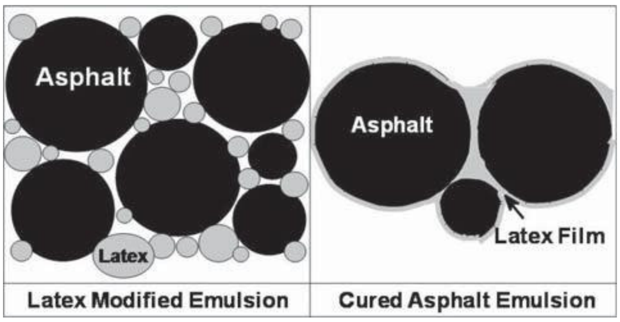


FIGURE 11 Emulsion with latex in dispersion and after breaking and curing (Watson 2005).

Typical emulsion specifications are shown in Table 16. These include binder content and residual asphalt properties. Both viscosity and storage stability are vital to ensure effective emulsion performance on the jobsite.

Aggregates

According to the National Highway Institute's *Pavement Preservation Treatment Construction Guide* (2007), the key characteristics of aggregates used in microsurfacing are as follows:

- **Geology:** This determines the aggregate's compatibility with the emulsion along with its adhesive and cohesive properties.
- **Shape:** The aggregates must have fractured faces in order to form the necessary interlocking matrix. Rounded aggregates will result in poor mix strength.
- **Texture:** Rough surfaces (crushed aggregate) form bonds more easily with emulsions.
- **Age and Reactivity:** Freshly crushed aggregates have a higher surface charge than aged (weathered) aggregates. Surface charge plays a primary role in reaction rates.
- **Cleanliness:** Deleterious materials such as clay, dust, or silt can cause poor cohesion and adversely affect reaction rates.
- **Soundness and Abrasion Resistance:** These features play a particularly important role in areas that experience freeze-thaw cycles or are very wet.

The physical properties of the aggregate are important to it achieving its design service life (Fugro-BRE/Fugro South 2004). The quality of microsurfacing aggregate is typically measured by the four properties shown in Table 17. The content analysis found that some agencies also specified the fundamental material from which the aggregate was made. A typical example from the Missouri DOT is as follows:

> The mineral aggregate shall be flint chat from the Joplin area, an approved crushed porphyry or an approved crushed steel slag. Blast furnace slag may be used from sources with a documented history of satisfactory use and that have been previously approved by MoDOT for use in micro-surfacing. For non-traffic areas such as shoulders, the mineral aggregate may be crushed limestone or crushed gravel (Missouri DOT 2004).

TABLE 16
TYPICAL PROPERTIES OF MICROSURFACING EMULSIONS

Test	Typical Specification	Method
Residue	62% min.	AASHTO T59
Sieve Content	0.3% max.	AASHTO T59
Viscosity at 77°F (25°C)	15–90	AASHTO T59
Stability (1 day)	1% max.	ASTM D244
Storage Stability (5 days)	5% max.	ASTM D244
Residue Penetration at 77°F (25°C)	40–90	ASTM D244
Elastic Recovery	5%–60%	AASHTO T301
Softening Point	135°F (57°C) min.	ASTM D5
Distillation at 350°F (177°C)	62% min.	ASTM D6997
Polymer Content	3.0% min.	ASTM D6372

Sources: National Highway Institute (2007) and ISSA (2010b).

Gradations

Table 18 shows the gradation for standard microsurfacing aggregates. ISSA (2010b) is the proponent of the A143 microsurfacing design method and is the source for the various type classifications of aggregates for both microsurfacing and slurry seals. The primary difference between the two gradations is top size, with Type III furnishing a coarser aggregate than Type II. The gradation determines the appropriate amount of residual asphalt in the mix design as well as the particular applications, such as rut filling, for which a given mix design is effective. Type II is recommended for "raveling and oxidation on roadways with moderate to heavy traffic volumes. Type III . . . is appropriate for filling minor surface irregularities, correcting raveling and oxidation, and restoring surface friction . . . on arterial streets and highways" (National Highway Institute 2007). The fines (i.e., aggregate particles 75 µm and finer) in the mix create "a mortar with the residual asphalt to cement the larger stones in place" (National Highway Institute 2007). Fines are essential for creating a cohesive hard-wearing mix. The National Highway Institute *Pavement Preservation Manual* (2007) recommends that the fines content be at the midpoint of the grading envelope. Additionally, a 2002 research study suggests that the distribution of the fraction that passes the #200 sieve (75 µm and finer) is critical in effectively controlling reaction rates in microsurfacing emulsions (Shilling 2002). This finding makes the amount of material that passes the #200 sieve an important gradation factor with regard to microsurfacing performance.

Surface Texture

Eight of the responses indicated that the agency used more than one gradation in their microsurfacing programs. Additionally, many of those that cited specifying a nonstandard gradation added an explanatory note that theirs was a slight modification of the standard gradations. One can see the split between Type II and Type III aggregates. When asked to identify the gradation that was most often specified, Type II was indicated more frequently than Type III and other gradations. The seeming preference for the smaller aggregate may have been caused by the concerns about road noise, which are discussed in detail in chapters seven and eight.

Type III aggregate will also produce a surface with deeper macrotexture, which will result in a surface that drains faster than Type II. Conversely, it will also produce more road noise. Road noise was the complaint most often reported in the survey. A study completed at the National Center for Asphalt Technology (NCAT) found that a "surface with a smooth texture using small maximum size aggregate" (de Fortier Smit 2008) reduced macrotexture and minimized road noise. Because Type II aggregate has a lower top size, it appears to conform to the NCAT finding. Therefore, the preference for Type II may also be to mitigate road noise complaints.

Mineral Filler

Portland cement or other fine materials are used as a "mixing aid allowing the mixing time to be extended and creating a creamy consistency that is easy to spread . . . hydroxyl ions counteract the emulsifier ions, resulting in a mix that breaks faster with a shorter curing time" (National Highway Institute 2007). Portland cement also has a fine consistency, which absorbs water from the emulsion and causes it to break faster. As previously discussed, fine materials in the mineral filler also promote cohesion by forming a mortar with the residual asphalt. The Minnesota DOT specification for

TABLE 17
GENERAL AGGREGATE PROPERTIES AND AGGREGATE REQUIREMENTS

Test	Microsurfacing	Test Number and Purpose
Sand Equivalent (min.)	65	ASTM D2419 Clay Content
Soundness (max.)	15%	ASTM C88 (using $NaSO_4$)
Abrasion Resistance	30% max.	AASHTO T96 Resistance to traffic
Crushed Particles	100%	ASTM D5821

Source: ISSA (2010b).

TABLE 18
MICROSURFACING AGGREGATE GRADATIONS (ISSA 2010b) AND USAGE FOUND IN THE SURVEY

Sieve Size	Percentage Passing		
	Type II	Type III	Stockpile Tolerance
3/8 (9.5 mm)	100	100	—
# 4 (4.75 mm)	90–100	70–90	±5%
# 8 (2.36 mm)	65–90	45–70	±5%
# 16 (1.18 mm)	45–70	28–50	±5%
# 30 (600 μm)	30–50	19–34	±5%
# 50 (330 μm)	18–30	12–25	±4%
# 100 (150 μm)	10–21	7–18	±3%
# 200 (75 μm)	5–15	5–15	±2%
Survey Usage			Other Gradation
U.S.	16	11	6
Canada	2	7	1
Total	18	18	7
Content Analysis Total	7	6	8
Grand Total	25	24	15

mineral fillers describes the mineral filler requirements as follows:

> Mineral filler shall consist of carbonate dust, Portland cement, hydrated lime, crushed rock screenings, fly ash, or rotary lime kiln dust, subject to approval by the Engineer . . . Crushed rock screenings to be used as mineral filler shall be of such composition and quality that the bituminous mixture containing the rock screenings will have stability and durability equivalent to those of the comparable mixture containing one of the other acceptable filler materials. The rock screenings shall be free from clay and shale (Minnesota DOT 2005).

Mineral fillers found in the study:

- Portland cement
- Hydrated lime
- Limestone dust
- Crushed rock screenings
- Fly ash
- Kiln dust
- Baghouse fines

Additives

Other materials are sometimes added to the microsurfacing mix. These additives vary and are often specific to proprietary microsurfacing systems. The National Highway Institute's *Pavement Preservation Manual* (2007) notes that additives normally act as retardants to the reaction with emulsions. Typical additives include emulsifier solutions, aluminum sulfate, aluminum chloride, and borax. Varying the concentration of an additive allows the contractor to control the breaking and curing times. For example, the contractor can change the concentration to account for increasing and decreasing air temperatures across the work day (Hicks et al. 2000; Caltrans 2007, 2008).

Additives found in the study:

- Aluminum sulfate crystals,
- Ammonium sulfate
- Inorganic salts
- Liquid aluminum sulfate,
- Amines
- Anti-stripping agents

The content analysis revealed that most microsurfacing specifications (87%) direct the contractor to include "additives approved by the emulsion manufacturer . . . to the emulsion mix or to any of the component materials to provide control of the set time in the field" (New Mexico DOT 2009) or a similarly worded specification clause. The survey also sought information on additives, and only one U.S. (Tennessee) and one Canadian agency (Nova Scotia) indicated that they require an anti-stripping agent. Thus, the following effective practice is identified:

> *Compounds added to microsurfacing job mix formulae can be selected by the emulsion manufacturer and the agency can then verify that they are compatible with the approved job mix formula.*

DEVELOPING AND LABORATORY TESTING OF A JOB MIX FORMULA

The development of a job mix formula fundamentally involves calculating the proportions of each component to the microsurfacing mix. ISSA A143 (2010b) is normally used as the guideline from which the job mix formula is completed. It starts by estimating the approximate proportions using ISSA *Technical Bulletin 102.* This entails creating a matrix of mix recipes and recording the manual mixing time for each option. During this operation, the technician looks for and visually assesses changes such as foaming and coating. The standard of

a minimum mixing time of 120 s at 25°C (77°F) is applied and the process is repeated at different temperatures to model performance in expected field conditions. The best mix is selected using aggregate coating as the prime criterion among those alternative designs whose mixing time exceeded the minimum across the expected temperature range (Moulthrop 2007).

The optimum emulsion content is selected and three new mixes are created. The first is at the percentage determined in the previous step and the other two are plus and minus 2% of that emulsion content to bracket the desired mix proportions. Next, cohesion build-up is tested in accordance with ISSA TB 139 and performed at the expected field temperatures. Table 19 contains the mix properties that are tested and compared. The optimum binder content is determined by plotting the output from the Wet Track Test (TB 100) and the Excess Binder Test (TB 109) and determining where the two curves intersect. This amount is subsequently adjusted using professional judgment to account for expected traffic volume (National Highway Institute 2007). The process demands an experienced designer to select the optimum binder content (Austroads 2003b).

Final testing of the job mix is conducted when its components have been selected. The final mix is tested to ensure it meets the specifications listed in Table 19. The emulsion content and aggregate grading are reported as the "job mix formula." Often adjustments within the allowable mix ranges need to be made to the job mix formula in the field to account for climatic variables encountered during installation. These field adjustments are "limited to the amount of additives (cement and retardant) and water content needed to ensure a good homogeneous mix at the time of application" (National Highway Institute 2007). A typical U.S. specification that describes the job mix formula process comes from Missouri:

> The manufacturer of the emulsion shall develop the job mix formula and shall present certified test results for the engineer's approval. The job mix formula shall be designed in accordance with the ISSA recommended standards by an ISSA-recognized laboratory. Mix acceptance will be subject to satisfactory field performance. The job mix formula, all material, the methods and the proportions shall be submitted for approval prior to use. Proportions to be used shall be within the limits provided . . . If more than one aggregate is used, the aggregates shall be blended in designated proportions as indicated in the job mix formula, and those proportions shall be maintained throughout the placement process. If aggregate proportions are changed, a new job mix formula shall be submitted for approval (Missouri DOT 2004).

This specification relies heavily on the microsurfacing contractor and its emulsion supplier to develop the job mix formula. The Missouri DOT rated the performance of its microsurfacing projects as "Good" in their response to the survey. In addition, the content analysis identified this agency as having the least prescriptive microsurfacing specification. Those two items of information, combined with the chapter two finding that most agencies make the microsurfacing contractor responsible for the job mix formula, indicate that microsurfacing is a good candidate for performance-based contracting.

APPLICATION RATES

Microsurfacing can be placed in relatively thick lifts. Table 20 contains the guidance found in an ISSA manual. However, it does have a maximum limit for Type III of 30 pounds per square yard (18.3 kg/m^2) when placed unconfined or with a spreader box. Excessive application rates may cause the mix to segregate and leave a flushed or excessively smooth surface texture. If the engineer needs to exceed the stated maximum application rates, the microsurfacing is then placed in multiple lifts. A study of microsurfacing's effectiveness as a rut filler was completed by the Alaska DOT and validated the application rates shown in Table 16 (McHattie and Elieff 2001). Getting application rates correct in the field is important as the production of the microsurfacing operation is constrained by the application rate. Additionally, the depth of the ruts to be filled also affects the application rate. ISSA states it as follows:

> The correct application rate of the treatment can have a pronounced effect on the success of the project. Excessive thickness can result in rippling, displacement, and segregation. Inadequate thickness can cause excessive raveling and reduced life (ISSA 2010a).

TABLE 19
TYPICAL MIX REQUIREMENTS

Property	Test (ISSA)	Microsurfacing
Wet-Track Abrasion Loss (wear loss)	TB 100 (1 hour soak)	50 g/SF (538 g/SM) max.
	(6 day soak)	75 g/SF (807 g/SM) max.
Wet Cohesion (traffic time)	TB 139 (30 minutes)	12 kg-cm min.
	(60 minutes)	20 kg-cm min.
Wet Stripping (adhesion)	TB 114	Pass 90% Minimum
Classification Compatibility (integrity)	TB 144	11 Grade Points Minimum (AAA, BAA)
Excess Asphalt by LWT Sand Adhesion (excess binder)	TB 109	50 g/SF (538 g/SM) max.
Lateral Displacement (deformation)	TB 147	5% max.

Source: ISSA (2010b).
LWT = loaded wheel tester.

TABLE 20
SUGGESTED APPLICATION RATES

Aggregate Type	Location	Suggested Application Rate per Pass
Type II	Urban and Residential Streets	10–20 lb/SY (5.4–10.8 kg/SM)
	Airport Runways	10–20 lb/SY (5.4–10.8 kg/SM)
	Scratch or Leveling Course	As required
Type III	Primary and Interstate Routes	15–30 lb/SY(8.1–16.3 kg/SM)
	Wheel Ruts	As required (see below)
	Scratch or Leveling Course	As required
Rut Depth		Application Rate
0.5–0.75 in. (12.7–19.1 mm)		20–30 lb/SY (10.8–16.3 kg/SM)
0.75–1.00 in. (19.1–25.4 mm)		25–35 lb/SY(13.6–19.0 kg/SM)
1.00–1.25 in. (25.4–31.75 mm)		28–38 lb/SY (15.2–20.6 kg/SM)
1.25–1.50 in. (31.75–38.1 mm)		32–40 lb/SY(17.4–21.7 kg/SM)

Source: ISSA (2010a).

SERVICE LIFE

Microsurfacing is normally used as a pavement preservation tool to extend the service life of the existing pavement. Thus, the service life of the microsurfacing is equal to the amount it extends the service life of the underlying pavement. Pittenger (2010) adjusted the classic service life concept for pavement design to the pavement preservation and maintenance domain. She posits that the service life of a pavement preservation treatment is one of two possible states:

1. Continuous: The treatment will remain [in place] until it fails.
2. Terminal: The treatment will be removed before the end of its continuous service life by a programmed rehabilitation or restoration project such as milling and overlaying (Pittenger 2010).

Pavement Life Extension

Ideally, microsurfacing service life would be at least as long as the period from the present to the given road's next scheduled rehabilitation, upgrade, or replacement. For example, an asphalt pavement overlay is nearing the end of its expected 10-year service and is scheduled to be rehabilitated in 4 years as part of a reconstruction project. The engineer selects a pavement preservation and maintenance treatment that can be expected to last at least 4 years to keep this road in full service. Table 14 lists Type II and Type III microsurfacing as having 2 to 4 years and 3 to 5 years of expected service life, respectively. Therefore, the engineer could select either as an appropriate treatment to extend the overlay's service life until its scheduled reconstruction in 4 years.

Service Life Determination

Table 21 shows the effective service life for the microsurfacing reported in the literature and the results of the survey responses regarding observed microsurfacing service life. The table shows broad agreement that the average service life of a microsurfacing application is 6 to 7 years. It is noted that both the literature and the survey response service life estimates are invariably presented with the caveat that the underlying road be in good condition. This provides further confirmation for the effective practice that microsurfacing not be used on structurally deficient roads.

SUMMARY

This chapter focused on the design of microsurfacing. It furnished information on the process found in the literature, the results of a microsurfacing specification content

TABLE 21
SUMMARY OF MICROSURFACING SERVICE FROM THE LITERATURE AND THE SURVEY

Source	Minimum Service Life	Maximum Service Life	Average Service Life
Bausano et al. (2004)	6	7	6
Lyon and Persaud (2008)	5	7	6
Smith and Beatty (1999)	7	10	7
Watson and Jared (1998)	5	7	6
Hicks et al. (1997)	5	7	6
Labi et al. (2007)	5	15	7
Temple et al. (2002)	4	10	7
Chehovits and Galehouse (20100	2	5	3.5
Average Literature	4.8	8.5	6
U.S. Survey Respondents	1	15	6
Canadian Survey Respondents	3	9	7
Average of Survey Responses	3.6	13	7

analysis and the corresponding results of the survey of highway agencies. The trends seen in these independent sources resulted in the identification of six conclusions and four effective practices.

Conclusions

1. Microsurfacing can be procured using a performance-based contract. The content analysis found that a number of agencies are already using performance specifications in their microsurfacing contracts.
2. Microsurfacing is a pavement preservation and maintenance tool with very few technical or operational limitations.
3. U.S. agencies are not maximizing the potential benefits of microsurfacing when they do not see it as the primary tool to fill ruts as their Canadian counterparts do.
4. The majority of maintenance practitioners do not consider environmental impact in their project development process
5. The majority of the respondents that use microsurfacing assign the contractor the responsibility for completing the job mix formula. The majority of the same population rated their microsurfacing project performance as satisfactory.
6. Microsurfacing can be expected to provide an average service life of 6 to 7 years if the underlying road is in good condition.

Effective Practices

1. Project selection is critical to microsurfacing success and those agencies that only apply microsurfacing to structurally sound pavements are generally satisfied with its performance.
2. Microsurfacing design can be successfully assigned to the microsurfacing contractor with the agency reviewing and approving the final job mix formula.
3. Microsurfacing performs best when applied to correct surface friction and/or rutting on pavements that have adequate structural capacity.
4. It is important that compounds added to microsurfacing job mix formulas are specific to the requirements of the emulsion manufacturer and that the agency verifies that they are compatible with the approved job mix formula.
5. Microsurfacing programs can be successfully implemented with a single binder type with a record of satisfactory performance in a given agency's climate and traffic conditions.

CHAPTER FOUR

CONTRACTING PROCEDURES

INTRODUCTION

The highway industry is based on construction contracting. Microsurfacing is no different than any other technology when it comes to the regulation of how public highway agencies can procure these services. Previous research has shown that contract policies, procedures, and regulations directly affect construction costs (Ohio DOT 2007; Erwin and Tighe 2008). Because contracts are used to allocate risk among the parties to a contract, understanding how design, construction, and performance risk is treated in microsurfacing contracts it is necessary to understand its market pricing and the depth of the pool of qualified contractors. Finally, competition affects construction costs and the lack thereof can put a pavement preservation and maintenance treatment that is economical in one market out of monetary reach in another.

This chapter will review findings as they relate to the policies, principles, and guidelines currently being followed by state transportation agencies to contract for microsurfacing. It will deal with the various contracting procedures that are used by the various agencies that responded to the questionnaire. The distribution of performance risk will also be discussed in this chapter. Additionally, those contractual mechanisms to ensure responsibility will be identified and discussed as they are found both in the literature and in the questionnaire responses. It will include the following:

- Contract types,
- Microsurfacing programs and their impact on competition,
- Training and certification programs for contractors and inspectors,
- Warranties, and
- Microsurfacing contract provisions.

CONTRACT TYPES

Transportation infrastructure contracts have traditionally been awarded using a low bid process that is often required by legislation at the state and local level. The survey identified two primary types of low bid contracts being used: unit price and indefinite delivery indefinite quantity (IDIQ). Although they also use unit price, the Missouri and New York DOTs both indicated using IDIQ contracts. IDIQ contracts are pre-priced contracts bid without knowing the exact project locations or amounts (North Atlantic Division 2006). These lend themselves well to maintenance contracting and are often called capacity contracts because the owner has a given capacity to satisfy microsurfacing requirements without having to prepare individual sets of biddable construction documents for each new project (North Atlantic Division 2006). These have a long history of use in the federal sector, but are rarely used by state and provincial DOTs.

CONTRACT ADMINISTRATION

The survey contained a specific section devoted to contract administration procedures. The output is shown in Table 22. The first few questions were designed to gauge the impact on competition for microsurfacing projects. It has been reported that some U.S. and Canadian agencies do not employ certain treatments in their pavement preservation programs because of a dearth of qualified contractors (Erwin and Tighe 2008; FHWA 2010a). Thus, being able to generate an adequate level of competition is one parameter in the pavement treatment selection process.

Microsurfacing Competition

The first noticeable trend is in the volatility of the agencies' microsurfacing programs. To be able to bid on a microsurfacing contract, the contractor has to have the appropriate equipment and personnel with enough experience to be able to achieve the production rates necessary to submit a competitive bid. The business case that is to be made for the investment in capital equipment and training has to be offset by a reasonable expectation to be able to recoup that investment with a profit using it on agency microsurfacing jobs (Small Business Administration 2009). Thus, more agencies answered "we rarely know how much microsurfacing we will use from year to year" than any other possible answer combined with the "no knowledge" answers (to total 10 of 36 replies) suggests that developing the capability to bid on microsurfacing contracts from those agencies is speculative at best.

The uncertainty in how much microsurfacing will be let from year to year will have a chilling effect on competition (Small Business Administration 2009). This phenomenon is validated by the fact that 33 of 36 total responses indicated they normally had 3 or fewer bidders and 22 of those responses indicated that they did not receive an "adequate number of qualified bidders." Adding to that is that virtually

TABLE 22
SUMMARY OF SURVEY GENERAL CONTRACTING INFORMATION

Question	U.S.	Canada	Total
Change in Annual Microsurfacing Program Volume?			
Virtually the Same Amount	5	3	8
Fluctuates ±20% Each Year	6	1	7
Fluctuates ±50% Each Year	1	1	2
Rarely Know How Much Each Year	9	1	10
No Knowledge	7	2	9
Typical Number of Bidders?			
1 to 3	25	7	32
4 to 6	2	1	3
7 to 9	1	0	1
Adequate Number of Qualified Bidders?			
Yes	12	2	14
No	14	6	20
No Opinion	2	0	2
Prequalified List of Eligible Bidders?			
Yes	11	0	11
No	14	8	22
Do Not Know	3	0	3
Required Training/Certification of Contractor Personnel?			
Yes	1	1	2
No	19	7	26
Do Not Know	8	0	8
Required Training/Certification of Agency Personnel?			
Yes	5	1	6
No	20	6	26
Do Not Know	3	1	4

all responding agencies outsource their microsurfacing work, which leads to the conclusion that most of the U.S. and Canadian agencies do not believe they have adequate competition among qualified microsurfacing contractors for their programs. The survey responses from those agencies that indicated satisfaction with the current level of competition came from agencies that also reported no more than a 20% fluctuation in their annual programs. This suggests that a possible remedy is for each agency to set aside a specific minimum amount of microsurfacing inside its annual pavement preservation and maintenance program to create an incentive for highway contractors to invest in the equipment and training necessary to increase the level of competition in this important sector.

Microsurfacing Qualifications

Table 22 also contains the survey results regarding required types of qualifications and/or training that would make a contractor eligible to be awarded a microsurfacing project. Finally, information on agency personnel microsurfacing qualifications, if any, was also sought. The rationale for these two sets of questions was to provide current information in support of the FHWA's Pavement Preservation Expert Task Group's strategic plan in which one goal was to develop a pavement preservation certification program for both contractor and agency personnel (FHWA 2010a). The idea of contractor and agency workforce development specifically in pavement preservation and maintenance has been around for at least a decade. One paper stated that: "Highway professionals need a better understanding of pavement preservation and maintenance benefits and the different maintenance categories" (Zaniewski and Mamlouk 1999).

Microsurfacing Training and Certification

The majority of the respondents answered the question regarding a prequalified microsurfacing bidders list in the negative. Comparing that response with the response reporting general agency dissatisfaction with the average number of bidders leads to a concern that perhaps the small number of potential bidders makes developing a microsurfacing prequalification program moot. Additionally, only two agencies require specific microsurfacing training or certification for their contractors. The Virginia DOT has its own slurry seal contractor certification program that applies to microsurfacing contractors. It consists of a 4-h class covering materials, equipment, proper placement procedures, and specifications, and it finishes with an examination. Manitoba has a general paving contractor certification program. These programs consist of a series of learning modules that cover the quality management requirements for each program. A slight increase is noted for training and certification of agency personnel, with six agencies answering positively to that question. Kansas, Nevada, Saskatchewan, Virginia, and Wyoming use in-house training programs and Missouri combines their in-house training with the web-based National Highway Institute pavement preservation course (NHI Course Number FHWA-NHI-131110A) for its microsurfacing personnel.

Caltrans has an on-going program called "Just In Time" (JIT) training that it associates with a number of construction means and methods. It requires existing certifications for selected construction processes as part of its general specifications. The following example for concrete could be applied to microsurfacing as a programmatic system to enhance both contractor and agency personnel qualifications.

> Mandatory training is part of the Caltrans specification. Caltrans requires Just-In-Time Training for the rapid-setting concrete pavement projects. Contractors and engineering personnel directly involved with these projects are required to attend. Once the training is completed, a one-year certificate is given to each participant (Feldman and Feldman 2007).

The responses to the three questions discussed previously coincide with the Pavement Preservation Expert Task Group initiative to develop a certification program at the national level found in the literature (FHWA 2010a) and allows one to conclude that a microsurfacing training and/or certification program is needed. Once implemented, certification would benefit the construction community by giving certified contractors a competitive advantage. Requiring DOT personnel to be certified would not only enhance agency quality control/ quality assurance (QC/QA) programs but also provide a common base of knowledge from which quality issues could be discussed between the contractor and the agency inspector.

WARRANTIES

Pavement warranties are controversial for at least two reasons. First, they are often proposed for projects where the contractor furnishing the warranty did not construct the pavement structure upon which the new pavement or surface treatment is constructed (Ohio DOT 2007). Second, the contractor normally has no input to the structural design process and therefore is asked to guarantee the risk that the design was adequate without any control over the magnitude of that risk (Austroads 2003a). Figure 12 illustrates the continuum of microsurfacing contract risk and relates the four categories to the type of contract risk that is inherent to each point on the continuum. Note that the three examples that are shown in the figure are not the only possibilities that can be observed. However, they do represent the majority of this study's findings in both the literature and the content analysis.

Owner agencies that require construction warranties may expect to pay a premium for that privilege (Ohio DOT 2007). However, this study found that 21 of 28 U.S. DOTs and 7 of 8 Canadian MOTs require the microsurfacing contractor to develop the job mix formula. As discussed in chapter three, this also involves characterizing the existing substrate. Therefore, the risk of warranting another's design disappears, and the risk associated with the existing conditions can be mitigated by merely examining the project site and deciding whether microsurfacing is an appropriate treatment. If it is not, the contractor makes a "no-bid" decision. Thus, because the classic level of uncertainty is reduced, a microsurfacing project shows the potential to be a better candidate for a warranty provision than other pavement preservation and maintenance treatments.

Critical Warranty Details

The survey asked each respondent to indicate whether or not they used warranties in their program and, if they did, to disclose the details of that warranty. Table 23 contains a summary of those responses, as well as each agency's rating of their microsurfacing performance. The results can be broken into two groups. The first are agencies that require a standard construction warranty of materials and workmanship (usually for 12 months) on all their contracts and the second are those that have written separate microsurfacing warranty provisions. Table 24 is an example of the supplementary specification that the Ohio DOT (2008) uses for its microsurfacing projects. A copy of this specification is contained in Appendix C to furnish all the details for the interested reader. Looking at the table, one can see that 8 in 28 U.S. and 7 of 8 Canadian agencies couple microsurfacing with warranties. Table 24 shows measurable threshold criteria developed by the agency to permit an objective evaluation of microsurfacing performance during the period of the warranty. Finally, because microsurfacing is most often used to extend the underlying pavement's life, the warranty creates a mechanism to ensure that purpose is accomplished. Therefore, it appears that warranting microsurfacing projects for which the contractor has furnished the job mix formula is not problematic to the same degree as other types of road construction.

Because warranties are often used to create an incentive for quality work (Thompson et al. 2002), comparing the agency's microsurfacing performance evaluation is instructive. Table 23 shows that 3 of the 4 "fair" ratings came from agencies with warranties. Therefore, the question of whether the warranty is an attempt to enhance the quality of the agencies' micro-

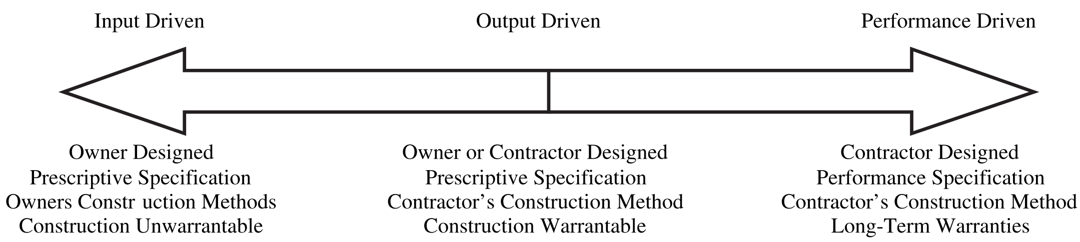


FIGURE 12 Contract risk continuum (Scott et al. 2006).

TABLE 23
SUMMARY OF WARRANTIES REPORTED IN THE SURVEY

Agency (state or province)	Warranty Length	Nature of Microsurfacing Warranty	Microsurfacing Performance Rating from Survey
Indiana	3 years	Friction, raveling, rutting	Fair
Louisiana	1 year	Materials and workmanship	Good
New Hampshire	1 year	Surface defects	Excellent
Nevada	2 years	Standard construction warranty	Good
New York	1 year	Delamination, snowplow damage, flushing, and raveling > 2.0 SY	Good
Ohio	2 years	See Table 24 for details	Good
Oklahoma	1 year	Standard construction warranty	Fair
Texas	2 years	Rutting, flushing, and raveling	Fair
Alberta	1 year	Adhesion (raveling)	Good
British Columbia	1 year	Standard construction warranty	Good
Manitoba	2 years	Performance specification includes warranty provision	Excellent
Nova Scotia	2 years	Standard construction warranty	Good
Ontario	2 years	Flushing, raveling	Good
Quebec	1 year	Standard construction warranty	Good
Saskatchewan	1 year	Standard construction warranty	Good

surfacing program or if the increased performance monitoring demanded by a warranted pavement surface has made the agency more aware of the defects that form in newly applied microsurfacing. The Ohio DOT's guidance for selecting micro-surfacing projects on which a warranty can be required highlights the need to carefully evaluate the pavement's existing condition before adding a warranty.

> This Item [warranty specification] can be used on minor rehabilitation projects which do not require a structural overlay . . . Projects which do not qualify for preventive maintenance nor have been designed in accordance with the minor rehabilitation requirements are not eligible for a warranty. High stress locations are not candidates for micro-surfacing . . . With warranty, however, it is more important that proper pavements be selected and the existing pavement is properly prepared, otherwise the warranty could be voided (Ohio DOT 2008).

Warranty Cost Experience

In 2007, the Ohio DOT published a cost analysis study of its warranty program that disproved that notion. It found over a three-year period that microsurfacing projects with a warranty had unit prices that were only 0.18% more than those without (Ohio DOT 2007). The same report contained information on the perceptions of the change in microsurfacing quality by Ohio DOT personnel, which showed that 69% believed the impact to be an improvement. Contractors were also surveyed as to what changed from their perspective and it showed that the top three contractor-perceived warranty-induced improvements were:

1. Quality conscious construction
2. Better workmanship
3. More design input (Ohio DOT 2007).

This connects with the notion introduced at the beginning of this section regarding risk exposure. The risk allocation changes when the contractor is allowed to have input to the design and that unit prices in Ohio did not skyrocket when warranties were introduced confirms the assertion that micro-surfacing projects are good candidates for warranties because the contractor has more control over the design and construction process. This confirms the Ohio DOT warranty guidance directing engineers to carefully select "proper pavements" for warranted microsurfacing projects.

TABLE 24
SUMMARY OF OHIO DOT MICROSURFACING WARRANTY SPECIFICATION

Distress Type	Threshold Level (per 500 SF of surface area)	Description
Bleeding/ Flushing	300 SF (28 SM)	Excess asphalt binder that creates a shiny, reflective condition that becomes tacky to the touch at higher temperatures.
Surface Loss	120 SF (11 SM)	Loss of surface interlock by traffic wear, debonding, or delamination.
Raveling	300 SF (28 SM)	"Moderate" level raveling as defined in the Strategic Highway Research Program (SHRP) "Distress Identification Manual for the Long-Term Pavement Performance Project" (SHRP-P-338).
Rutting	0.25 in. (6.5 mm) continuous in any segment	Measure the wheel path with a 4 ft (1.2 m) straight edge. Only applies during the first 120 days after the Form C-85 is issued.
Maintenance Bond	2 years	75% of the amount bid for the microsurfacing pay item.

Source: Ohio DOT (2008).

MICROSURFACING CONTRACT PROVISIONS

Often contracting provisions can have a large impact on pavement preservation and maintenance treatment performance. For example, a Texas study found that agencies that paid for crack sealing by the linear lane-mile rather than by the pound of sealant had fewer flushing issues in their seal coat programs because the unit price by weight created an incentive for the crack sealing contractor to use as much crack seal as possible to boost the total amount paid (Senadheera et al. 2001), whereas paying by the lane-mile had the opposite effect, but required a higher level of quality assurance to make sure all cracks were sealed. Another example from that study was the finding that seals installed early in the season had less early raveling than the ones placed late in the season because early seals had more high surface temperature traffic compaction, which kept the binder softer (Senadheera et al. 2001). Therefore, it is important to evaluate key contract provisions to look for similar trends in microsurfacing.

This section will look at the following contract provisions:

- Seasonal restrictions
- Pay units
- Incentive/disincentive clauses

Seasonal Considerations

Microsurfacing is an asphalt-based product and as a result is sensitive to ambient air temperature, humidity, wet conditions, and surface temperature. "The basic prerequisite for success is that the emulsion needs to properly break and cure. As a result, humidity, wind conditions, and temperature (both surface and air) are important and need to be considered" (ISSA 2010a). Therefore, the microsurfacing contract needs to account for the restrictions that the material places on the environment in which it can be applied with good results. The specification content analysis accumulated weather-related provisions. Table 25 shows the most typical climate-related contract provisions regarding temperature limits within which microsurfacing can be applied. Most revolve around the typical temperature for hot-mix paving operations: 50°F (10°C) and rising. The three that were lower than that limit were the Ohio DOT at 40°F (4°C) and Michigan DOT and FLHD at 45°F (7°C). Kansas and Wyoming DOTs require the temperature to be above 60°F (16°C) and Louisiana uses 70°F (21°C). The functional effect of lower temperature requirements is to extend the microsurfacing season, which is necessary for agencies in northern climes such as the three mentioned. Louisiana is the only southern agency that does not use that specification. No explanation could be found for the reason that the Louisiana Department of Transportation and Development uses 70°F (21°C). Wyoming's use of a higher than standard temperature (60°F; 16°C) stems from the concept that it is the Rocky Mountain state where temperature gradients are much steeper than those found in northern states in the Midwest and farther east. In the Rockies, the temperature can vary ±40°F (±4.4°C) in mid-summer and more if the road is at a high altitude. Therefore, the Wyoming DOT is building a safety factor into its specifications to meet the demands of local climate.

Research has found the surface temperature affects the rate at which an emulsion breaks (Moulthrop 2007). Figure 13 shows the relationship between temperature and emulsion breaking time. One report indicated that it would be necessary that surface temperatures be within a range of 50°F (10°C) and 140°F (60°C) to ensure a proper break (Gransberg and James 2005). When the emulsion breaks too fast, wash-boarding can occur, and if it breaks too slow, the product becomes susceptible to raveling (Moulthrop 2007; ISSA 2010a). All the specifications reviewed also contained a further requirement to the effect that the minimum temperatures needed to occur in conjunction with a period of no fog, rain, drizzle, or forecast of freezing temperatures within the next 24 h. Therefore, it is important the microsurfacing contract include air and surface temperature requirements that match both the materials to be used and the climatic conditions in which they will be applied.

The other common climatic constraint found in the specifications was a definition of the microsurfacing season. Most run from May to September, with the season being shortened as the location of the agency moved north. The survey asked the respondents to identify the months in which they authorize microsurfacing operations. Figure 14 is a histogram showing the frequency of response for the United States, Canada, and the total population. When the combined population is summed, 63% of all microsurfacing occurs in June, July, and August, with 100% being completed from April to October. None of the responding agencies applied microsurfacing from November through March.

TABLE 25
SUMMARY OF CONTENT ANALYSIS SPECIFICATION TEMPERATURE LIMITS

Specification Limit	States Using Specified Air Temperature Limit	States Using Specified Surface Temperature Limit
None	No states	AL, KS, NE, NM, PA
>45° (7.2°C)	FLHD, MI	FLHD, MI
>50° (10°C)	AL, GA, MN, MO, NE, NM, OH, OK, PA, TN, TX, UT, VA	AL, GA, MN, MO, OK, OH, TN, TX, UT, VA
>60° (15.6°C)	KS, WY	No states
>70° (21.1°C)	LA	LA

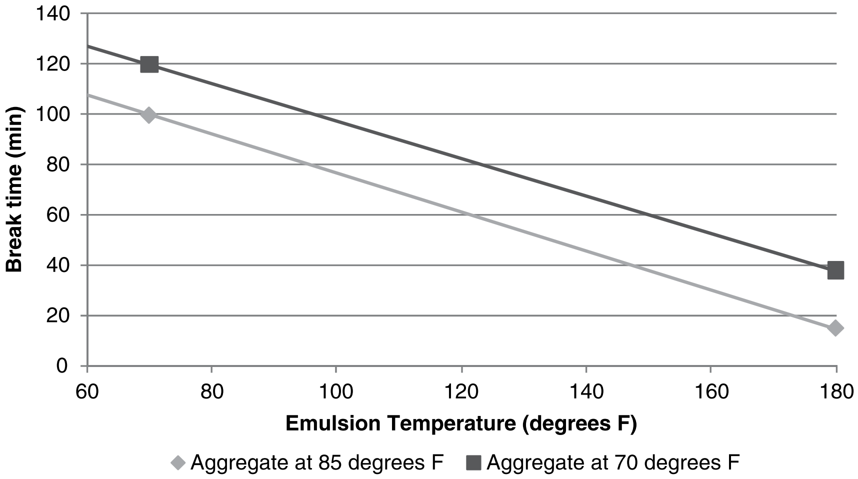


FIGURE 13 Relationship between temperature and emulsion breaking time (ISSA 2010a).

Figure 15 shows the distribution if the respondents are split between northern and southern climates. It reveals that microsurfacing is more intense in the shorter northern season, whereas the southern states are able to spread their program out over a several more months. This puts the issue of qualified microsurfacing contractor availability into a time context. The northern agencies complete their annual programs between mid-May and mid-September; therefore, it is essential that the number of new lane-miles of microsurfacing be placed at a faster rate in the north, creating a seasonally higher demand for qualified contractors in the north than in the south.

Taking the location of those agencies in North America that require microsurfacing warranties shown in Table 23 into account, one finds that 12 of 15 are northern states or Canadian provinces. The common trend in these three sources leads to two identified effective practices:

1. *Agencies in northern climates can mitigate potential quality issues induced by a short microsurfacing season by requiring a warranty.*
2. *Scheduling microsurfacing project letting as early as possible will permit their completion as early in the season as possible and mitigate the risk that poor weather at the end of the season will adversely impact microsurfacing quality.*

Contract Payment Provisions

"Unit price contracts are used for work where it is not possible to calculate the exact quantity of materials that will be required. Unit price contracts are commonly used for heavy/highway work" (Schexnayder and Mayo 2004). When an owner selects unit price contracting, it is doing so to share the

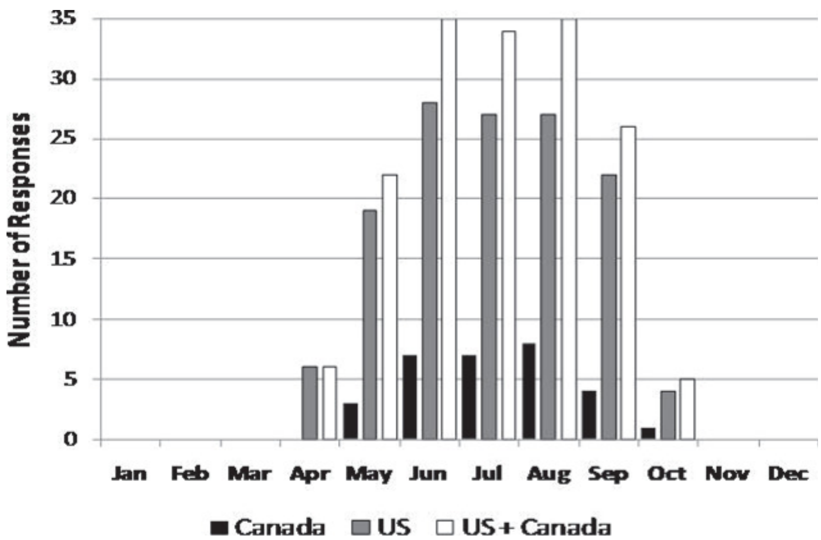


FIGURE 14 U.S. and Canadian microsurfacing season comparison.

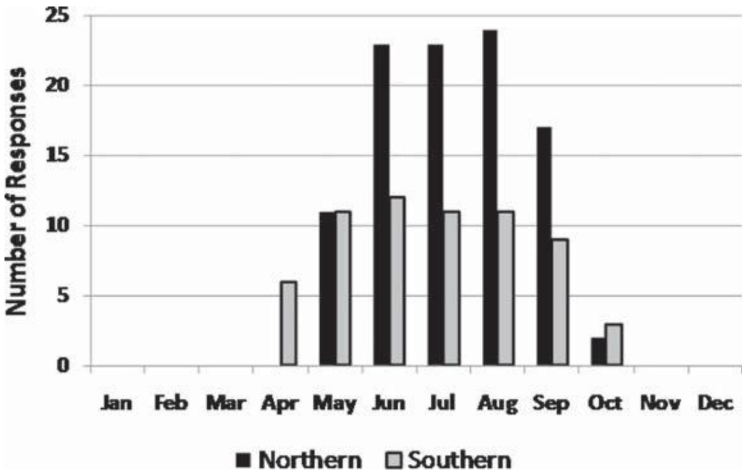


FIGURE 15 Northern and southern agency microsurfacing season comparison.

risk of the final quantities of work with the contractor to reduce the price. This happens because the contractor does not have to bid the worst possible case if the quantities of work are not finite as it would be driven to do in a lump sum contract where it bore the entire quantity risk (Schexnayder and Mayo 2004). The owner assumes the risk of quantity overruns by agreeing to pay for the actual units applied, rather than paying a premium for transferring the risk of quantity overruns to the contractor through a lump sum price. Given that microsurfacing projects usually are limited to a defined area of pavement, quantity surveys are fairly straightforward and not highly variable. Thus, lump sum contracts, including the total cost of the project with mobilization and traffic control, could be used without the agency incurring a substantial cost increase. For instance, the British Columbia MOT reported getting excellent results since the mid-1980s from lump sum microsurfacing contracts (Miquel and Condron 1991). That being said, no survey respondents indicated that they procured microsurfacing with lump sum contracts.

The survey found an almost even split between specifying pay units by area and by weight (see Table 26). Most respondents added a note to the effect that they do not differentiate between the binder and the aggregate, but rather use a single pay measure for microsurfacing. It also found that these were used because of perceived fairness and the ability to accurately measure pay quantities. The literature shows that the pay unit follows the type of specification used for the pay item (Schexnayder and Mayo 2004). Microsurfacing that is delivered using a performance specification can then be paid for by the area, because the amount of material installed to meet the performance requirements is left to the contractor (Erwin and Tighe 2008), whereas an agency using a method specification would pay by the ton, because the agency has taken control of the specified application rates (Price 2010). Based on the literature and survey results, the following effective practice is identified:

Microsurfacing is to be paid for by the ton if the agency is not using a performance specification.

The second parameter that affects unit prices is the quantity of work on the project being bid. As the amount of work that is packaged in a single contract increases, its unit price decreases because the contractor is able to spread the fixed costs, such as mobilization and traffic control across more units (Schexnayder and Mayo 2004). The survey found that the average U.S. microsurfacing project was 7.4 lane-miles (11.9 lane-km), with the low of 2 lane-miles (3.2 lane-km) and a high of 17 lane-miles (27.4 lane-km). In Canada, the average microsurfacing project was roughly the same at 6.8 lane-miles (11 lane-km), with the low of 3.7 lane-miles (6 lane-km) and a high of 17 lane-miles (12.4 lane-km). The point made here is that pavement managers can stretch microsurfacing budgets

TABLE 26
SUMMARY OF MICROSURFACING UNITS OF MEASURE AND THEIR RATIONALE

Pay Item Unit of Measure	Reduces the Cost		Fairest to the Contractor		Easier to Accurately Estimate		Do Not Know Why We Use Them	
Binder	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada
Units of Area (SY/SM)	1	0	3	2	4	3	3	0
Units of Weight (ton/tonne/MG)	2	0	4	0	4	2	2	0
Aggregate	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada
Units of Area (SY/SM)	2	0	2	1	4	4	3	0
Units of Weight (ton/tonne/MG)	1	0	7	0	7	2	1	0

by packaging projects with as much lane-mileage as is practical (Erwin and Tighe 2008). This agreement between the literature and the survey provides an effective practice:

Make microsurfacing contract packages as large as is practical to reduce the unit price and increase the number of lane-miles that can be treated each year.

This practice links with the finding in the previous section regarding a perceived lack of competition in the industry. Agencies that responded to having a reasonably consistent annual microsurfacing program generally were satisfied with the level of competition. Therefore, increasing the size of microsurfacing projects would also serve to enhance the consistency within a given program by permitting the agency to more effectively utilize its pavement preservation and maintenance budget.

Incentive/Disincentive and Quality Price Adjustment Clauses

One means to create a contractual mechanism that promotes early completion or quality is the use of an incentive/disincentive (I/D) provision or a quality price adjustment (QPA) provision in the measurement and payment clause of the microsurfacing contract (Laungrungrong et al. 2007). The I/D provision would normally apply to the project schedule and pay a bonus for finishing early or a penalty for being late. The QPA provision operates on the theory that the agency is willing to pay the contractor on a basis that is commensurate with the actual quality of the delivered product. Therefore, if the final product exceeds the performance criteria, the contractor will be paid an additional amount. The provision works in the other direction as well. "However, negative price adjustments can provide a basis for accepting and paying for work that does not fully meet specifications and removal and replacement is not justified. They are not to penalize a contractor, but rather to pay an equitable amount for the value of the product delivered" (FHWA 2006).

Because state and provincial microsurfacing projects are usually installed on active highways where minimizing disruption is one of the objectives to the contract, I/D provisions are appropriate (Gao 2010). The Michigan DOT "found that the average net reduction in contract days was 19% in comparison with similar projects that were let with an expedited schedule clause requiring the contractor to work a six calendar-day work week, but without the use of an I/D provision" (FHWA 2006). Microsurfacing is also a product that has a number of material quality and performance features that can be measured. The same physical parameters that are shown in Table 23 for warranties could also be used as criteria in QPA provisions.

The survey and the content analysis looked for evidence of I/D or QPA provisions in microsurfacing practice. The survey had three responses, Michigan, Utah, and Wyoming, that indicated that they used QPA provisions. The pay formula was based on the job mix formula and the percent within limits found during QC/QA testing. Because those three states' microsurfacing specifications were included in the content analysis, it was able to validate the survey response.

SUMMARY

This chapter has summarized the salient aspects of microsurfacing contract formation and administration. The conclusions and effective practices are discussed here.

Conclusions

The following conclusions were reached:

- Most of the U.S. and Canadian agencies do not have an adequate level of competition among qualified microsurfacing contractors for their programs. This may be because most microsurfacing programs do not advertise a consistent amount of work each, making it difficult for interested contractors to develop the technical capacity and equipment necessary to competitively bid on these contracts.
- The concept of requiring warranties on microsurfacing projects was found to be less onerous than for other pavement work because most agencies require the contractor to furnish the job mix formula.
- Few agencies require microsurfacing contractors and agency personnel to complete microsurfacing training and/or a certification program. This indicates a need for such a program and, therefore, the FHWA Pavement Preservation Expert Task Group initiative to develop a microsurfacing certification program at the national level is both timely and valuable.

Effective Practices

The following effective practices were identified:

- Agencies in northern climates can mitigate potential quality issues induced by a short microsurfacing season by requiring a warranty.
- Scheduling microsurfacing project letting as early as possible will permit its completion as early in the season as possible and mitigate the risk that unstable weather at the end of the season will adversely impact microsurfacing quality.
- Microsurfacing is to be paid for by the ton if the agency is not using a performance specification.
- Make microsurfacing contract packages as large as is practical to reduce the unit price and increase the number of lane-miles that can be treated each year.

CHAPTER FIVE

CONSTRUCTION PRACTICES

INTRODUCTION

Construction practices and procedures vary from region to region and are generally associated with the climatic conditions in which the microsurfacing will be applied. This chapter will draw information from both the survey and the specification content analysis to identify those construction practices that are associated with successful microsurfacing projects.

CONSTRUCTION PROCESS

The *Pavement Preservation Treatment Construction Guide* (National Highway Institute 2007) asserts that the primary components of the construction process are as follows:

- Safety and traffic control
- Equipment requirements
- Stockpile and project staging area requirements
- Surface preparation
- Application conditions
- Types of applications
- Quality issues
- Post-construction conditions
- Post-treatments.

Safety and traffic control will be discussed in chapter six along with equipment requirements and stockpile and project staging area requirements. Quality issues and post-treatment performance will be covered in chapter seven.

Surface Preparation

Surface preparation's purpose is to furnish a clean and sound surface on which the new microsurfacing is installed and to which the microsurfacing will bond (New Mexico DOT 2009). As with most pavement preservation treatments, the agency needs to complete necessary crack sealing and patching. "Crack sealing provides the most cost-effective use of dollars over time compared to other pavement maintenance techniques" (Nebraska DOR 2002). Shortly before microsurfacing, the road is swept clean of foreign materials. Sometimes this requires the use of high power pressure washing if clay or other hard-to-remove materials, such as organic matter, are present. Failure to remove contaminants may lead to delamination of the treatment in the contaminated areas. Road markings are also removed or abraded to produce a rough surface before placing microsurfacing. Paint markings require no pretreatment. Rubber from skid marks is also removed. Utility inlets can be covered with heavy paper or roofing felt to prevent the microsurfacing from interfering with their proper operation. Additionally, "all starts, stops, and handwork on turnouts should be done on roofing felt to ensure sharp, uniform joints and edges" (Caltrans 2009).

The content analysis found that 100% of the specifications reviewed contained a requirement to thoroughly clean the surface of the road. In addition, all the specifications included a requirement to pre-wet the road's surface before beginning microsurfacing. The pre-wetting process was described in one specification as "Pre-wet the surface by spraying water ahead of and outside of the spreader box at a rate that dampens the surface without allowing water to flow freely ahead of the spreader box" (Georgia DOT 2001). Another common practice was the requirement to spray a tack coat before microsurfacing, which was found in 7 of 18 specifications sampled in the content analysis. The tack coat application rates ranged from 0.05 gallon per square yard to 0.25 gal/y^2 (0.25 to 1.5 l/m^2). ISSA (2010a) recommends that the tack coat consist of CSS-1h, although some of the specifications in the content analysis required SS-1h. The Michigan DOT specifications (2005) require a "bond coat" and the New Mexico DOT requires a "paint binder" as a tack coat on concrete pavement surfaces (New Mexico DOT 2009). Both of these are a less diluted emulsion binder. For example, SS-1h diluted to 50:50 was applied at a rate of 0.10 gal/y^2 (0.45 l/m^2) over jointed concrete pavement in the Kansas DOT (Moulthrop et al. 1996).

Application Conditions

It is widely recognized that weather-related factors are often responsible for the failure of a newly constructed microsurfacing (WSDOT 2003; Olsen 2008). Although microsurfacing

Agencies that require tack coats:

- Alabama
- Georgia
- Michigan
- Minnesota
- Ohio
- Pennsylvania
- Tennessee

emulsions depend on a chemical set to develop their adhesion characteristics, air temperature, relative humidity, wind velocity, and precipitation will impact the constructability of microsurfacing (ISSA 2010a). Ideal microsurfacing weather conditions are those with low humidity, a slight breeze, and with sustained high temperatures into the forthcoming days (National Highway Institute 2007). High humidity is a detriment to any microsurfacing owing to its acting to retard the breaking of the emulsion (Asphalt Institute 1988). ISSA recommends that microsurfacing only be placed if the humidity is 60% or lower (ISSA 2010a). The Georgia DOT specification allows microsurfacing placement up to 80% relative humidity (Georgia DOT 1998) and the New Mexico DOT specification limits humidity to no more than 50% (New Mexico DOT 2007).

Hot temperatures accelerate the set and increase the need to use spray bars to fog the surface, which cools the surface and keeps the emulsion from breaking on contact (Caltrans 2009). Additional water may also be needed in the mix to "counteract the higher pavement temperatures and dehydration in the spreader box" (ISSA 2010a). When temperatures are high, the operator might need to accelerate the ground speed of the microsurfacing machine and/or decrease the rate at which the materials are mixed in the pug mill. A common rule of thumb is to set a production rate that corresponds to a mix dwell time in the spreader box of 45 s or less (Wood 2007).

Figure 16 summarizes the results of the content analysis. The majority fall at or above 50°F (10°C). The two that were less come from Michigan and the FLHD. The net effect of permitting a lower temperature is to functionally extend the construction season. Michigan's northern geography makes this understandable. However, the geographic working area for the three FLHDs is the national parks and other federally owned land. Much of this land is in the mountainous areas of the country and hence logic for a slightly lower than average temperature has the same impact as in Michigan.

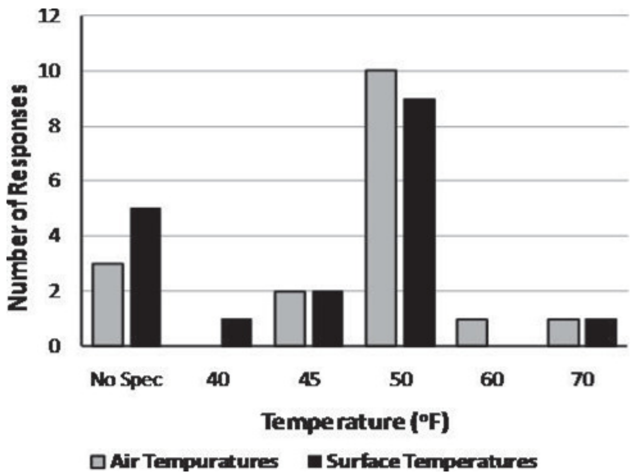


FIGURE 16 Summary of U.S. and Canadian ambient air and surface temperature specifications.

Types of Applications

There are four types of microsurfacing applications:

1. Full lane width
2. Scratch coat
3. Rut filling
4. Hand-applied.

Full-Lane Width Microsurfacing

This is the most common type of microsurfacing application. When applying a full width seal a standard spreader box such as the one shown in Figure 17 is used. The National Highway Institute *Pavement Preservation Treatment Construction Guide* (2007) describes the process for installing a full lane-width microsurfacing in the following manner:

> The edge of each pass should align with the longitudinal joints or paint lines on the roadway. Three passes are typically used for a two-lane roadway. This allows clean edges and minimizes overlaps (usually 75 mm (3 in)). Overlapped seals should only be used when the pavement being sealed is level and in sound condition.

Keeping the spreader box level and pulling it smoothly without vibration is the key to installing a full-width microsurfacing free of surface discontinuities. The ISSA *Inspector's Manual for Slurry Systems* (2010a) summarizes the issues surrounding spreader box operation in this manner:

- Cleanliness is mandatory in a spreader box. The box must be cleaned at the end of every work period and may require cleaning (especially the rear rubber) during the work day if excessive buildup of mixture causes streaking in the finished surface (mat).
- The spreader box should not leak the mixture. Side rubbers (where appropriate) should be installed so that edges are kept neat. The rear box rubber (or steel) should leave a uniform thickness and strike off the mixture so that there are no uneven

FIGURE 17 Full lane-width microsurfacing (*Courtesy:* Intermountain Slurry Seal, Inc. 2010).

Keys to Microsurfacing Success:

- A clean spreader box
- No leaks
- Pulled smoothly and evenly
- No vibration

FIGURE 18 Scratch coat diagram (ISSA 2010a).

ridges or longitudinal ripples left in the mat. The rear rubber may be changed in thickness, width, and hardness to achieve desired results.

- The spreader box should pull smoothly and evenly without vibration. Machine speed should be kept uniform. Excessive speed can cause the box to vibrate or jump, leaving transverse ripple lines in the finished surface. If using a drag, excess speed can cause it to leave a rippled and uneven mat. Spreader boxes of different designs react differently to spreading stresses. A normal speed on one type may be an excessive speed on a different box. The most important factor in determining the allowable speed of application is the end result and quality of the treatment. Laying speed is also affected by application rate, gradation of aggregate, viscosity of the mixture, and existing surface conditions, both texture and smoothness (ISSA 2010a).

Scratch Coats

"For irregular or shallow rutting less than ½ inch depth (1.26 mm), a full-width scratch coat pass may be used as directed by the project manager [for] each individual rut fill . . . [r]uts that are in excess of 1–½ inches (3.8 mm) depth may require multiple placements with the rut filling spreader box to restore the original cross section" (Labi et al. 2007). Figure 18 illustrates the theory behind this. All pavements suffer some degree of rutting during their service life. Structurally sound pavements can rut owing to consolidation of the asphalt surface in the wheel paths (Hicks et al. 2000). Concrete pavements will develop minor ruts over time owing to abrasion in the wheel paths and both will rut in areas where studded snow tires are authorized for use (Washington State DOT 2009). Both pavements can become uneven in the transverse direction as well. ISSA (2010a) describes these as "minor transverse irregularities and longitudinal ruts less than 0.5 inches (12.5 mm) deep." The objective of the scratch coat is to create a uniformly level surface upon which to apply the surface course of full-width microsurfacing. Scratch coats are applied with a steel, rather than rubber, strike-off to ensure that the resulting surface is as level as possible (Price 2010).

The survey asked respondents to indicate whether or not they used a scratch coat when the substrate conditions warranted one. There is a school of thought that believes that the aggregate in the scratch coat be a different size than that used on the full-width microsurfacing (Caltrans 2009). Therefore, the survey also asked that question. Table 27 shows the results from that question. Quebec and Missouri both decrease aggregate size for the scratch coat and both rated their microsurfacing performance as "good." Illinois ("fair" performance rating) and Michigan ("good" performance rating) increase it. Oklahoma ("fair" performance rating) checked "other" and changes the application rate of the mix on the scratch coat. Virginia's "other" indicated that it could go either way. Virginia also rated its microsurfacing as "good." The trend here is quite clear and leads to following effective practice:

Scratch coat and full-width microsurfacing can use the same size aggregate with no apparent difference in performance.

Rut Filling Applications

Microsurfacing's major advantage is its ability to fill ruts in an effective manner (Wood and Geib 2001). A rut box such as the one shown in Figure 19 is an essential piece of equipment because it is designed to channel the mix directly into the ruts. Its strike-off is also designed to leave a crowned finish to compensate for compaction by traffic after installation. As a rule, ruts are filled and then covered with a full-width microsurfacing, but they can be opened to traffic without one

TABLE 27
SUMMARY OF SCRATCH COAT SURVEY RESPONSES

Question	U.S.	Canada	Total
Do you use a scratch coat when conditions warrant?			
Yes	23	6	29
No	4	2	6
Do not know	0	0	0
If yes, is the aggregate size different in the scratch coat?			
No change in scratch coat aggregate size	17	5	22
Scratch coat aggregate is smaller	1	1	2
Scratch coat aggregate is larger	2	0	2
Do not know	1	0	1
Other, please specify	2	0	2

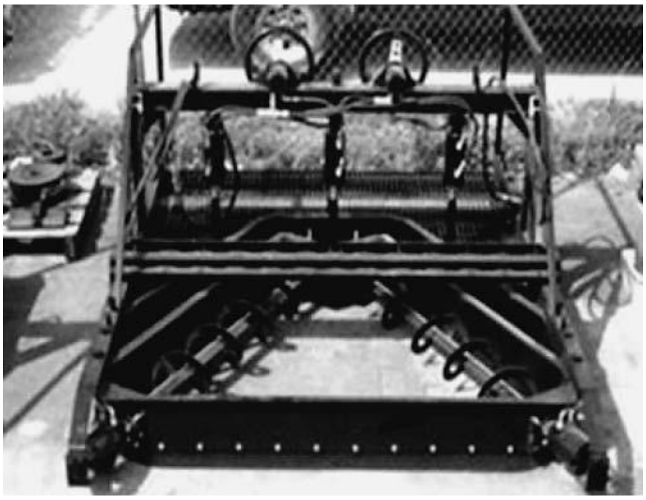


FIGURE 19 Rut box (*Courtesy:* Bergkamp Inc. 2010).

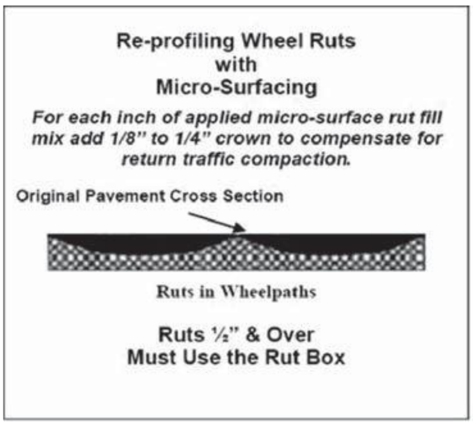
(Labi et al. 2007; New Mexico DOT 2009). Some agencies require newly filled ruts to be rolled to compact the mix placed in rutted surfaces (Main Roads 2008; PennDOT 2009). Several authors (Smith and Beatty 1999; Province of Ontario 2009; ISSA 2010a) recommend that newly filled ruts be trafficked to compact them for at least 24 h before covering them with the final microsurfacing course.

Figure 20 illustrates the principles upon which rut filling is based. "Rut filling should only be used on stable ruts that have resulted from long-term traffic compaction rather than failures in the base or sub-base" (New Mexico DOT 2009; ISSA 2010a). "If rutting is the result of defects that cannot be treated (i.e., failure in the subbase or subgrade), filling the ruts with microsurfacing will not prevent development of ruts in the future. If the ruts are caused by an unstable pavement layer material or a structurally deficient pavement layer, the source of the original rutting problem generally will cause the rutting to return very quickly" (Smith and Beatty 1999). It is noted that failing to fill ruts as a separate step in the microsurfacing process will impact application rate. "A single rut of even minor deformation will increase the total average application rate as the rut must be filled to the level of the existing pavement during the application process" (ISSA 2010a).

Table 28 is a consolidation of the literature on rut filling and when it is appropriate. It furnishes a set of guidelines for incorporating rut filling into a typical agency pavement preservation and maintenance program. Figure 21 shows before and after pictures of an appropriate use of microsurfacing for rut filling on Interstate 90 in eastern Washington State. The ruts were the result of mechanical abrasion from studded tires, and were nearly 1 in. (25.4 mm) deep after only 6 years of service. The pavement was structurally sound. The ruts were flat and no fatigue cracking was evident in the wheel paths. Therefore, this was a good candidate for rut filling with microsurfacing (Washington State DOT 2009).

Hand Work

Most projects have areas of pavement that are not accessible to the spreader box. These areas will be covered using handheld squeegees or lutes (New Mexico DOT 2007). Although microsurfacing these areas has the same technical requirements as the rest of the pavement, aesthetics is generally the primary problem. The goal is to match the surface texture to the machine-laid microsurfacing. Therefore, if the spreader box uses a drag mop, drag mops need to be attached to the hand tools to obtain a matching surface texture (ISSA 2010a). Because hand work is substantially different from the rest of the process, its quality is driven by the amount of time the workers have to spread the mix before it breaks (ISSA 2010a). Therefore, because emulsions break faster at higher temperatures, it is advisable to schedule hand work in the cooler hours of the day, if possible, to give the workers the maximum amount of time to not only spread the mix where it needs to go but also achieve the desired texture match. Additionally, the surface of the pavement where the hand work will take place needs to be wet before starting. This reduces



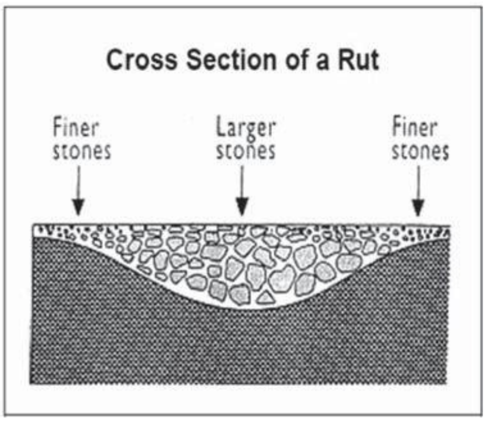


FIGURE 20 Rut filling diagram (ISSA 2010a).

TABLE 28
LITERATURE SUMMARY OF APPROPRIATE CHARACTERISTICS FOR RUT FILLING

Surface Distress Characteristic That Favors the Use of Rut Filling	ISSA (2010a)	NHI (2007)	NM DOT (2007)	Penn DOT (2009)	WS DOT (2009)	Smith and Beatty (1999)
Pavement is structurally sound	X	X	X	X	X	X
Rutting is due to mechanical compaction of pavement structure	X	X				X
Ruts are flat, not sharp or showing dual wheel marks	X				X	X
Ruts do not contain fatigue cracking	X	X	X	X	X	X

the pavement's surface tension, making it easier to push the mix around and level it off. ISSA adds this important caveat to its manual regarding hand work:

> The cardinal rule for handwork is 'least is best.' The more the mix is worked, the more segregation takes place. As the squeegee moves the matrix back and forth the larger aggregate is worked to the surface while the fines may be lost and the mix can dehydrate. The coarse aggregate is then inadequately embedded and may ravel. Large areas requiring handwork are necessarily applied in small sections, allowing sufficient time to place and finish the material without causing segregation or sizeable areas to break (ISSA 2010a).

Post-Construction Conditions

The first post-construction issue that is planned is removing traffic control and opening the newly sealed surface to traffic. Before trafficking is allowed, the emulsion must be allowed to break and the mix must cure. The ambient temperature and humidity will affect the overall curing time. Warming temperatures and low humidity reduce the time it takes for the emulsion to break and expel the water. On the other hand, cool, humid conditions increase curing times and delay opening to traffic. Currently, the chemical change can only be seen rather than measured; ISSA has collected two empirical tests that permit the observer to estimate whether or not traffic control can be removed.

- The Stick Test—"The asphalt emulsion should begin to break no more than 30 to 45 s after the mixture is deposited by the spreader box. A small stick drawn across the deposited mixture will tear the surface and if the tear cannot be smoothed over by the stick the break has occurred.
- The Shoe Test—The shear strength and bond can be checked subjectively by placing your full weight flatly on the sole of your shoe on the placed treatment. If the sole can be placed on the new treatment for 2 s without picking up aggregate, then the pavement can be opened to rolling traffic without significant negative effects. If you can place your weight on the heel of one shoe on the placed treatment and twist the heel (about 180°) with only minor surface marks and without the large aggregate being displaced, the mixture can probably be opened to turning traffic without significant damage. However, sharp turns, especially by heavy vehicles, can damage micro-surfacing for some time after application, particularly in hot weather" (ISSA 2010a).

FIGURE 21 Microsurfacing applied to rutting caused by studded tires in Washington State: before and after (Washington State DOT 2009).

The above-mentioned tests are hardly scientific in that they require an experienced person to conduct them with some degree of reproducibility. This points to the need for research to develop a suite of field tests that allow an inspector to test the microsurfacing mix after it has been laid as well as tests to identify when the mix has cured to a sufficient degree to open it to traffic without fear of damaging it.

Microsurfacing can normally handle rolling traffic without damage less than one hour after placement (Price 2010). However, in areas such as intersections where stop and go traffic is prevalent, additional curing time may be needed, especially during unexpectedly hot or cold weather (National Highway Institute 2007). Microsurfacing emulsions can retain some water for several weeks. If during this period freezing temperatures are experienced, the binder film will rupture and the surface will ravel. As a result the Caltrans *Maintenance Technical Advisory Guide* (MTAG) recommends that projects "not be started" unless there is a "2-week window" without freezing weather in the forecast (Caltrans 2009). Another concern is that asphalt emulsions "cannot re-emulsify if not fully cured, but they can be tender enough to re-disperse under the effects of traffic loading and excessive water, especially ponded water. In this process, broken aggregates or asphalt particles that have not fully coalesced into films are dispersed in water, which disintegrates the emulsion" (Caltrans 2009). Microsurfacing can typically withstand a light rain 3 h after application. However, a heavy rain and heavy traffic will damage the surface, especially in areas with shear resulting from turning movements (Caltrans 2009).

Post-Treatments

The ISSA inspector's manual (ISSA 2010a) contains information on two post-microsurfacing treatments that are cogent to the discussion. The first is sweeping to remove excess stone on heavily trafficked roads, which ISSA recommends be done with a suction broom if possible and completed before opening the road to traffic. Sweeping is also needed if excessive stone loss is experienced after opening a heavily trafficked road. The second treatment is sanding, which can be used to furnish extra protection for special areas such as intersections. Wet spots can also be sanded to permit their opening to traffic. Sanding can commence as soon as the microsurfacing can support traffic without pick up (Caltrans 2009).

SUMMARY

This chapter reviewed the microsurfacing construction process from concept to traffic opening. Two types of spreader boxes were discussed in detail, but these are mere appurtenances that are attached to other pieces of construction equipment, and that is the subject of the next chapter. One effective practice was developed:

> *Scratch coat and full lane-width microsurfacing can use the same size aggregate with no apparent difference in performance.*

CHAPTER SIX

MICROSURFACING EQUIPMENT PRACTICES

INTRODUCTION

To a great extent, the equipment used in the construction phase drives the quality and performance of microsurfacing during its service life (Bergkamp 2010). Therefore, it is critical that the construction equipment system be well defined and capable of controlling the construction means and methods critical to the performance of the product. Construction practices and procedures vary from region to region and are generally associated with local equipment availability and empirical knowledge of its use. This chapter draws information from both the survey responses and the specification content analysis to identify those microsurfacing equipment practices that are associated with successful projects. Constraints that are contractually articulated are identified, categorized, and reported to allow the reader to easily note the range in philosophies that naturally occur across the nation and the world. Special attention has been paid to method specifications that prescribe specific construction equipment or that serve to enhance equipment operation.

MICROSURFACING EQUIPMENT TRAIN

The microsurfacing equipment train is designed around producing the job mix in the machine that lays it down on the roadway (see Figure 1 in chapter one). This occurs in a purpose-built machine that may either be self-propelled or mounted on a truck. Therefore, all the other pieces of equipment support the production of the microsurfacing placement machine (Nebraska DOR 2002).

Most agencies will find the following types of equipment on a typical microsurfacing project:

- Microsurfacing mixing (also called a placement) machine,
- Mobile support units (also called nurse or feeder trucks) to replenish the materials in the mixing machine,
- Broom sweepers—rotary or suction, and
- Rollers, if required—pneumatic or static.

Some agencies are careful to specify the equipment characteristics that are of specific interest in their construction specifications. Others prefer to use a performance specification and allow the contractor the latitude to pick and choose its equipment as long as the final product conforms to specified performance criteria. An example of a method specification for microsurfacing equipment specifications was found in the Georgia DOT manual and is as follows:

- Blend the paving mixture using a self-propelled microsurfacing mixing machine that is:
  - A continuous flow mixing unit.
  - Able to accurately deliver and proportion the aggregate . . . emulsion, mineral filler, field control additives, and water to a revolving multi-blade, twin shafted mixer.
  - Able to discharge the mixed product on a continuous flow.
  - EXCEPTION: Blending the paving mixture may be accomplished with a truck mounted microsurfacing mixing machine that meets the above specification, except for continuous flow, when placing the mixture on short streets or projects that are less than one-half mile (800 m) in length.
- For streets or projects less than one-half mile (800 m) in length, individual truck-mounted units may be used for placement of microsurfacing. For streets or projects one-half mile (800 m) or greater, in length, place microsurfacing mixture with a machine that is equipped as follows:
  - Has self-loading devices that load raw materials while continuing to lay micro-surfacing, thereby minimizing construction joints.
  - Has opposite side driving stations to optimize longitudinal alignment.
  - Allows the operator to have full hydrostatic control of the forward and reverse speed while applying micro-surfacing material (Georgia DOT 2001).

The Kansas DOT uses the following performance specification:

> Mix and spread the microsurfacing materials with a self propelled machine capable of accurately delivering and proportioning all of the required components. Operate the machine continuously while loading, eliminating construction joints (Kansas DOT 2008).

Microsurfacing Mixing Machine

Figure 22 shows pictures of the continuous self-propelled and the truck-mounted mixing machines. The major difference is that the continuous machine can have its hoppers replenished while on the move. Thus, transverse construction joints are minimized to those areas where the machine has to stop moving for some reason. The truck-mounted machine has to stop to have its ingredients replenished.

Table 29 shows a summary of the requirements for microsurfacing mixing machines found in the survey and content analysis. It shows that continuous self-propelled machines are preferred, but that a large proportion of agencies accept both.

FIGURE 22 Continuous front-loaded self-propelled (*left*) and truck-mounted (*right*) microsurfacing mixing machines (*Courtesy:* Bergkamp Inc. 2010).

Two respondents, California and Illinois, indicated that they would probably exclude the use of a truck-mounted mixing machine on projects where long stretches of road are to be microsurfaced. The above-cited Georgia DOT specification is an example of one where the truck-mounted machine can only be used on short lengths of microsurfacing. Figure 23 shows how a mobile support unit replenishes the self-propelled continuous mixing machine as it moves down the road applying microsurfacing.

The mixing process is tied to the application rate of the mix. Application rate is controlled by instrumentation that ties together the emulsion pump, the gate settings on the aggregate, and some form of controller for the dry additives. The survey asked if computerized controls such as the ones shown in Figure 24 were specified by each agency in the population. In the United States, seven agencies answered that they do, whereas in Canada the number was four.

Calibration of Microsurfacing Machinery

To ensure that the mix contains the specified proportions of its ingredients the mixing machine need to be calibrated (ISSA 2010a). Additionally, calibration of individual machines is necessary because of the continuous feed nature of the mixing machine (Minnesota DOT 2005). To achieve a homogenous mix, it is important that the materials be delivered to the pug mill in the correct proportions. When calibrating, it is important to remember that the job mix formula is based on the "combined weight of dry aggregate and dry mineral filler (if used). Corrections for moisture in the aggregate could be necessary" (ISSA 2010a). Calibration accomplishes the following tasks:

- It sets the machine to the specified job mix formula.
- It strives to maintain consistency with respect to the design on all mixing equipment if more than one is used for a given job.
- It permits the benchmarking of data output from the calibrated machine (ISSA 2010a).

Table 30 contains the ISSA-recommended procedures for calibrating the emulsion pump and the feed rates of the aggregate and the mineral filler. Each make of mixing machine will have its own method for feeding dry additives to the pug mill (National Highway Institute 2007). Some use a system that is mechanically connected to the head pulley. These will use a gate setting that is very similar to the one on the aggregate belt. Another makes use of a system that is hydraulically matched by means of a ratio meter. These have a hydraulic flow adjustment that must be checked. Additionally, emulsion pumps vary from manufacturer to manufacturer.

> Pumps are either a fixed positive displacement pump or a variable positive displacement pump that can be mechanically set to various rates of flow. Since a variable volume pump will normally not be changed during the project, a calibration is necessary only for the setting that the contractor intends to use. Variable volume pumps should be equipped with a lock to avoid accidental changes and should be locked in place once calibration is completed. Calibrate emulsion to the head pulley count which is displayed on the rock/aggregate counter (ISSA 2010a).

TABLE 29
SUMMARY OF MIXING MACHINE REQUIREMENTS

Mixing Machine Requirement	U.S.	Canada	Content Analysis
Continuous self-propelled	14	2	18
Truck-mounted	0	0	0
Both	11	5	0
Do not know	1	1	0
Require specific model/make	0	0	0
Do not require specific model/make	23	7	3
Do not know if required or not	3	1	0

FIGURE 23 Continuous front-loaded self-propelled being resupplied by a mobile support unit (*Courtesy:* Bergkamp Inc. 2010).

The survey collected information on the practice of microsurfacing machine calibration. The results are shown in Table 31. U.S. agencies favor field calibration to certified laboratory calibration by a margin of 2 to 1, although the specification content analysis was evenly split. One-half the Canadians calibrate in the field, whereas three Canadian agencies do not specifically require calibration of any sort.

Preparing Test Strips

Even with calibration there is the possibility that the materials in use could measurably impact the design application rate (Wood 2007). ISSA (2010a) provides four factors that influence actual application and need to be taken into consideration in the field:

1. Adherence to the job mix formula aggregate gradations is critical. Often the designated aggregate gradations may vary in particle size distribution. For example, a Type II aggregate from one supplier may be finer than a Type II aggregate from another supplier and thus could easily be applied lighter. Aggregates produced by different types of crushers from the same parent rock may produce different shaped particles. For instance an impact crusher will produce nugget-shaped particles while a cone crusher will produce flat and elongated slivers.
2. Aggregates may vary in unit weight and a thicker application of one rock may actually weigh less than a thinner application of another. It is important to recalibrate the placement machine(s) for changes in aggregate sources.
3. Surface texture [of the substrate] will affect the application rate. A smooth surface does not have as many voids to fill and thus keeps the spread rate at a minimum. A weathered, raveled, open surface will increase the spread rate as the material fills the voids at the same time it is covering the surface.
4. Surface textures will often vary on the same road between traffic areas and shoulders or centerline areas. Application rates will vary with surface texture and thus may vary across any given cross section of a pavement (ISSA 2010a).

Many specifications account for these variations after calibration by requiring the construction of a test strip before allowing the contractor to begin full production microsurfacing. The content analysis discovered that roughly 40% of the

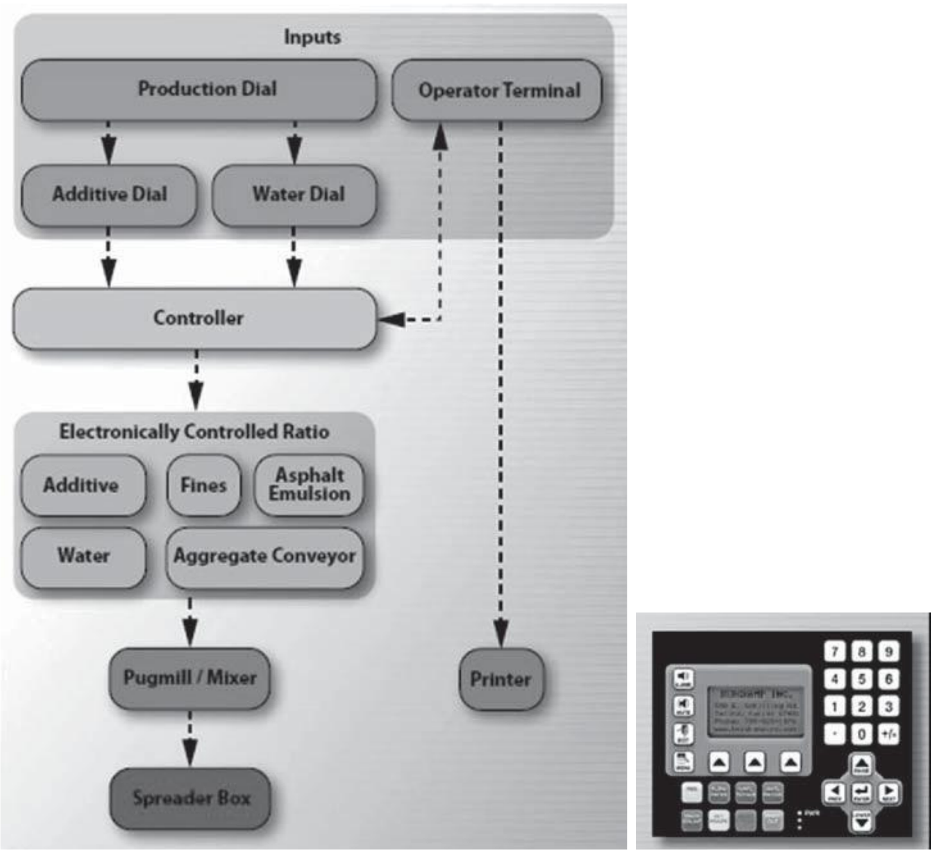


FIGURE 24 Typical microsurfacing machine computer control system and logic (*Courtesy:* Bergkamp Inc. 2010).

TABLE 30
MICROSURFACING CALIBRATION PROCEDURES

<table>
<tr><th>Asphalt Emulsion Calibration Procedure</th><th>Aggregate Calibration Procedure</th></tr>
<tr><td>1. Empty machine of all aggregate. Fill the placement machine with emulsion and measure the gross weight on a platform scale.
2. Hook pump outlet to a second container capable of holding 600 to 700 gallons (2,270 to 2,650 liters), such as a distributor or mobile support unit.
3. Run a minimum of 50 counts (if 50 counts are obtainable) on the rock/aggregate counter.
4. Determine weight of emulsion pumped by reweighing the placement machine.
5. Determine the weight of emulsion pumped per count on the rock/aggregate counter.
6. Run three tests to ensure accurate results. If variable displacement pumps are used, once calibrated they must be locked to stay constant with the JMF. Consult the manufacturers recommendation for the use of variable displacement pumps on placement machines. Calibration will have to be done for enough settings to establish a straight line graph.
7. The emulsion pump should deliver emulsion to the pug mill with such volumetric consistency that the deviation for any individual delivery rate check run shall be within 2% of the mathematical average of three runs of at least 300 gallons (1,135 liters) each.</td><td rowspan="3">1. Test the moisture of the aggregate. Calculate the moisture factor.
2. Moisture factor is the percent (in decimal format) of moisture in the aggregate + 1.00.
3. Select and record three gate openings and graph.
4. Oversized aggregate should be removed by screening prior to loading into the transport vehicle or placement machine. Weighing the aggregate should be completed after the screening operation.
5. Run at least 3 tons of material per gate setting, recording the net weight conveyed and the number of counts of the rock belt for three test samples, each a minimum of 50 counts.
6. The placement machine should deliver such volumetric consistency that the deviation for any individual aggregate delivery rate check-run shall not exceed 2% of the mathematical average of three runs.
7. Determine the average dry weight per count as per the rock calibration worksheet and plot the results to the graph. If a plotted straight line is not acquired on the graph, re-run the tests.
8. Set gate to the desired setting.
9. Run a small amount of material past the gate to establish the flow and fill the gate. Remove any excess material.
10. Weigh the placement machine. (Note all weights and counts.)
11. Reset the rock/aggregate counter to zero.
12. Run material out of the machine and stop the belt just as the counter changes to a new count to avoid partial counts.
13. Remove from the belt any excess material that has passed the gate but may not have fallen into the pug mill. Re-weigh the placement machine. The net weight of run divided by the count of the rock/aggregate counter provides pounds of aggregate per revolution of the head pulley.</td></tr>
<tr><th>Dry Additive/Mineral Filler Calibration Procedure</th></tr>
<tr><td>1. Check that all aggregate is removed from the placement machine as the conveyor belt must turn while calibrating the fines feeder.
2. Use a small pan or other container to catch the mineral filler that falls from the feeder. Weigh this container prior to performing the next steps.
3. Using the rock/aggregate counter to count the turns of the head pulley or the fines feeder auger, run out approximately 10 counts of material into the container.
4. Weigh the container of material and subtract the weight of the container. The weight of material divided by the count of the rock/aggregate counter or the fines feeder gives weight per turn.
5. Repeat at three settings to develop a curve for the material at various gate settings.
6. Calculate the desired setting to meet JMF requirements, set the gate or hydraulic controls, and verify the delivery rate.</td></tr>
</table>

Source: ISSA (2010a).
JMF = job mix formula.

microsurfacing specifications required the construction of a test strip. These ranged from 500 to 1,000 ft (152.4 to 304.8 m) in length. The purpose of the test strip is not only to validate that the calibrated machine is dispensing the precise amount of mix, but it is also to demonstrate the contractor's ability to properly construct transverse and longitudinal joints (Wood 2007). It also allows the agency to observe and measure, if necessary, the texture of the final mix after calibration. It also allows field determination of break and cure time. The Louisiana DOTD had the most complete specification in the analysis regarding microsurfacing test strips:

> The contractor shall place a 1,000' test strip with the microsurfacing material for each different roadway condition based on the approved job mix formula . . . Acceptance of the test strip will be based on construction technique, mixture stability, longitudinal and transverse tolerances, yield and texture. The test strip will be

TABLE 31
SURVEY RESULTS ON CALIBRATION PRACTICES

Location of Calibration	U.S.	Canada	Content Analysis
Field Calibration	15	4	8
Contractor Furnishes a Calibration Certificate	7	1	8
No Calibration	1	3	1
Do Not Know	0	0	1

approved by the engineer prior to continuation of construction (Louisiana DOTD 2006).

This specification was selected as a good example because it called out the performance measures that will be checked for acceptance. Additionally, it recognizes that roadway conditions will vary from site to site and a one-size-fits-all test strip will not account for this type of variation. Finally, it supports the quality assurance program by requiring the contractor to price the test strip(s), thereby creating an opportunity to solve product quality issues before they occur on a large scale.

The Minnesota DOT requires that the test strip be constructed after dark, presumably to ensure that full production microsurfacing can be conducted at night without quality degradation. Minnesota DOT also adds: "Carry normal traffic on the test strip within one hour after application, without any damage occurring. The Engineer will inspect the completed test strip after 12 hours of traffic to determine if the mix design is acceptable" (Minnesota DOT 2009). The Minnesota test strip not only tests the calibration of the machine and the contractor's workmanship, but also conducts a short-term field test of the job mix formula itself. These two specifications and the ISSA recommendations lead to the following effective practice:

Requiring a test strip of 500 to 1,000 ft (152.4 to 304.8 m) in length be constructed and accepted allows the agency and the contractor to ensure that the equipment is properly calibrated and that any workmanship issues are resolved before full-scale microsurfacing production. If the microsurfacing is scheduled to occur after dark, the test strip is to be constructed after dark.

The final aspect of using test strips to validate the calibration of the microsurfacing machinery is the requirement that the machine be recalibrated every time there are changes in material sources (Minnesota DOT 2009). This notion accounts for the actuality that materials that were used to prepare the job mix formula will necessarily change as the project progresses. "To assure that the slurry system treatment is constructed consistent with the JMF [job mix formula], the placement machine(s) *must be calibrated using the actual project materials*" (ISSA 2010a). Often the samples used for the laboratory tests that lead to the mix formula will come from stockpiles where the aggregate was crushed and stockpiled for some time. However, in the middle of the microsurfacing season, the aggregate is more likely to be freshly crushed and, as such, will have marginally different properties than the test samples that necessitate a recalibration to maintain the desired application rate and job mix formula (Wood 2007). A number of the survey respondents added a comment to their calibration frequency answer that validated the information found in the literature. This leads to the following effective practice:

The microsurfacing placement machine is to be recalibrated every time there is a change in material source or composition.

Brooms and Rollers

Brooms and rollers are support equipment for a microsurfacing project. The brooms are used before laying the microsurfacing to clean the road's surface of foreign debris and materials. They may also be used after construction is complete to remove excess aggregate from spillage and raveling. The suction broom is generally used for post-project clean-up because it puts less shear stress on the newly laid surface than the rotary broom. Figure 25 has pictures of both machines.

Rollers come in two standard types: pneumatic tired rollers and static steel rollers. It appears that the use of this piece of equipment is not standard across the U.S. and in Canada. ISSA (2010b) recommends that microsurfacing used to fill deep rutting be rolled using a 10- to 12-ton pneumatic roller. Nevertheless, there seems to be no agreement as to whether or not rolling adds value to the microsurfacing process. The survey found that most agencies do not require rolling (see Table 32). The ISSA *Recommended Guideline for Microsurfacing* (2010b) contains the following clause regarding rolling:

Rolling is usually not necessary for microsurfacing on roadways. Airports and parking areas should be rolled by a self-propelled,

FIGURE 25 Typical rotary broom (*left*) and suction broom (*right*) (*Courtesy:* Broce Inc. 2010).

TABLE 32
MICROSURFACING ROLLER REQUIREMENTS BY AGENCY

Roller Requirements	U.S./State	Canada/Province	Specification Content Analysis/State
Static Steel	1/NC	0	1/AL
Pneumatic Tired	7/AL, NC, NV, NY, OK, PA, VA	1/NS	4/AL, OK, PA, VA
Combination Pneumatic/Steel	1/NC	2/NS, QB	0
No Rollers Specified	17	5	13

> 10-ton (maximum) pneumatic tire roller equipped with a water spray system. All tires should be inflated per manufacturer's specifications. Rolling shall not start until the microsurfacing has cured sufficiently to avoid damage by the roller. Areas which require rolling shall receive a minimum of two (2) full coverage passes (ISSA 2010b).

The Quebec MOT added an interesting comment to its answer to this question when it stated it only uses rolling to "accelerate the curing period." A follow-up revealed that the agency believes that because rolling promotes embedment that the road can be opened to traffic earlier than without rolling. This appears to run parallel to the ISSA recommendation that "airports and parking areas should be rolled . . ." Presumably, the purpose is to promote greater embedment or adhesion and thus at an airport rolling would reduce the amount of foreign, objects, and debris (FOD) that could damage a jet engine. Parking lots are low-volume facilities and hence will not experience as much traffic compaction as a road, making rolling desirable. Going any deeper into this question is beyond the scope of this report; however, it does beg the question of whether or not rolling has any impact on microsurfacing performance, and hence makes a good area in which to conduct future research.

SUMMARY

Good microsurfacing products are impossible without well-calibrated and well-functioning equipment. Because microsurfacing is an equipment-intensive activity, special attention is necessary for the machines that will ultimately make microsurfacing a profitable pavement maintenance and preservation tool. The next chapter will focus on how to employ the tools and techniques of this and previous chapters to produce a high-quality microsurfacing product. The following effective practices were identified in this chapter:

1. Requiring a test strip of 500 to 1,000 ft (152.4 to 304.8 m) in length be constructed and accepted allows the agency and the contractor to ensure that the equipment is properly calibrated and that any workmanship issues are resolved before full-scale microsurfacing production. If the microsurfacing is scheduled to occur after dark, the test strip is to be constructed after dark.
2. It is important that a microsurfacing placement machine be recalibrated every time there is a change in material source or composition.

CHAPTER SEVEN

QUALITY CONTROL AND QUALITY ASSURANCE AND PERFORMANCE MEASURES

INTRODUCTION

A key element of microsurfacing projects is the quality control and quality assurance (QC/QA) philosophy and procedures applied. In both cases, an independent assurance element may be applied. QC/QA is a major issue with the highway agencies that are considering implementing contract pavement maintenance. This topic also relates to microsurfacing performance risk allocation that was covered in chapter four. Because microsurfacing design is laboratory-based and those tests were covered in chapter three, this chapter will confine itself to the construction QC/QA process. Specific QC/QA testing requirements for both the materials and the finished product are summarized and analyzed in this chapter.

QUALITY DEFINITIONS

For the purposes of this synthesis, *Transportation Research Circular E-C074: Glossary of Highway Quality Assurance Terms* (Committee on Management of Quality Assurance 2005) will be used to define the quality assurance terms in this report. Quoted here are the major definitions.

- **Quality.** The degree to which a product or service satisfies the needs of a specific customer, or the degree to which a product or service conforms to a given requirement.
- **Quality assurance (QA).** All planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. (QA addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, QA involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities).
- **Quality control (QC).** Also called process control. Those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product.
- **Independent assurance (IA).** A management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product and/or the reliability of test results obtained from process control and acceptance testing. (The results of independent assurance tests are not to be used as a basis of product acceptance.)
- **Verification.** The process of determining or testing the truth or accuracy of test results by examining the data and/or providing objective evidence. [Verification sampling and testing may be part of an independent assurance program (to verify contractor QC testing or agency acceptance) or part of an acceptance program (to verify contractor testing used in the agency's acceptance decision).]
- **Quality Management (QM).** The totality of the system used to manage the ultimate quality of the design as well as the construction encompassing the quality functions described above as QA, QC, independent assurance, and verification (Committee on Management of Quality Assurance 2005).

MICROSURFACING QUALITY REQUIREMENTS

Field quality management in microsurfacing consists of two primary activities. First, the contract for the project will specify a certain amount of QC/QA sampling of materials for testing to occur in the field. The primary reason for field sampling is to verify that the materials being installed conform to the same standards as in the contract. For example, on large microsurfacing projects where the aggregate and other materials are produced over a series of weeks rather than all at one time, the inherent variability that occurs in nature can change the engineering properties of aggregate and emulsion (ISSA 2010a). Thus, field sampling seeks to ensure consistency of the mix as it is being applied. The second major quality management activity is the monitoring and correcting of defects in workmanship. A perfect microsurfacing mix that has passed all the laboratory tests can still be improperly installed in a manner that prevents it from reaching its desired service life. "Therefore, good decisions and careful quality control are necessary from initial selection of the treatment type through final acceptance of the completed project" (Jahren and Behling 2004).

Field Testing Practice

The survey and the content analysis specifically sampled for information on how public highway agencies distribute the responsibility for conducting various quality management tasks. At this point it is important to remember from chapter three that most agencies assign the responsibility for

TABLE 33
SURVEY RESULTS ON FIELD QC/QA PRACTICES

Quality Management System	U.S.	Canada	Specification Content Analysis
Inspection Responsibility?			
Agency	28	6	18
Consultant	0	1	0
Contractor	0	1	0
Use of Independent Lab to Verify Job Mix Formula?			
Yes	3	0	0
No	21	8	18
Do not know	4	0	0
Field Sampling/Testing?			
Yes	20	5	10
No	5	3	8
Do not know	3	0	0
Field Testing Responsibility			
Agency	15	3	15
Consultant	5	0	0
Contractor	0	2	0
Not specified	0	0	3
Source of Field Acceptance Tests?			
Source/pit	2	2	10
Stockpile	15	4	6
While transferring to nurse units	1	0	0
Before entering the mixing machine	1	1	0
Do not know/not specified	3	1	4

developing the job mix formula to the microsurfacing contractor. This changes the classic QC/QA relationships. *NCHRP Synthesis 376: Quality Assurance in Design-Build Projects* (Gransberg et al. 2008) found that shifting design responsibility from the owner also shifts some of the traditional QA responsibility. Therefore, one would expect to see some level of involvement of the contractor in the QA as well as the QC process and a higher use of contractor test results in the QA program.

Table 33 illustrates the output from the survey and content analysis with regard to the division of responsibilities between the agency and the contractor. It shows that all U.S. and most Canadian agencies retain the traditional inspection responsibilities. However, only three agencies in the entire sample require independent verification of the job mix formula based on test results. All U.S. agencies also retain the traditional role with regard to performing their own field tests with either agency personnel or a consultant retained on the agency's behalf. This is not the case in Canada, where two of five agencies assign that task to the contractor. Agencies in Australia and New Zealand use performance-specified maintenance contracts, which make construction testing less important than in a traditional construction or maintenance contract (Manion and Tighe 2007).

Laboratory Testing Practice

Table 34 is a summary of the microsurfacing-related laboratory tests that were identified in the survey and the content analysis. No conclusions or effective practices can be drawn from this analysis. Therefore, it is presented for information purposes only.

QUALITY OF MICROSURFACING WORKMANSHIP

As with all paving contractors, microsurfacing contractors bid their projects based on a calculated rate of production. If the contractor does not complete the number of lane-miles each day that its bid is based on, then the contractor's profit is at risk. When this happens, the tendency to speed up to catch up becomes almost overwhelming, possibly causing a deepening disregard for the quality of the workmanship. Therefore, it is important to both the agency and the contractor that unnecessary delays and/or interruptions in production be minimized if possible. The construction of test strips discussed in chapter six is a good technique to alleviate technical differences of opinion as to what constitutes acceptable quality before the contractor begins full-scale production. Another tool that is often used is inspection checklists that both the agency's inspector and the contractor's QC manager have to allow both parties to check and verify that important details have been accomplished before starting production. A copy of one such checklist authored by the FHWA (2010) is contained in Appendix C.

Quality Assurance Focus

QA theory advocates identifying those areas that are of particular concern before starting construction and jointly addressing them in a preconstruction meeting (Austroads 2003b). The ISSA *Slurry Systems Inspector's Manual* (2010a) contains a list of preconstruction meeting objectives, which includes a discussion of QC/QA issues. The Minnesota DOT's microsurfacing specification (2009) echoes the need for this type of conference and prescribes a "Pre-Paving Meeting" of

TABLE 34
SURVEY RESULTS ON LABORATORY QC/QA TESTING PRACTICES

Test	U.S.	Canada	Specification Content Analysis	Total Occurrences
Residual Asphalt Content	18	6	18	42
Sand Equivalent	17	3	12	32
Wet-Track Abrasion Test ISSA TB 100	15	4	11	30
Wet Stripping Test ISSA 114	12	5	10	27
Softening Point	14	5	7	26
Penetration	12	5	8	25
Mix Time Test ISSA TB 113	12	4	9	25
Classification Test ISSA TB 144	11	4	8	23
Modified Cohesion Test ISSA TB 139	11	4	6	21
Loaded Wheel Test ISSA TB 109	9	3	7	19
Abrasion Resistance	9	2	6	17
Lateral Displacement Test ISSA TB 147	7	5	5	17
Soundness	11	1	4	16
Cure Time Test ISSA TB 139	6	2	3	11
Tests for the Presence of Clay	6	2	2	10
Percent Sodium Sulfate Loss (resistance to freeze/thaw)	6	0	4	10
Compatibility of Aggregate with Binder	5	3	2	10
Set Time Test	4	1	3	8
Consistency Test ISSA TB 106	3	1	1	5
TTI Mixing Test	1	0	1	2

similar nature to the one discussed in the ISSA manual. The National Highway Institute's *Pavement Preservation Treatment Construction Guide* does a thorough job of synopsizing main areas of microsurfacing workmanship quality concern as listed here.

- **Longitudinal Joints:** Longitudinal joints may be overlapped or butt jointed. They can be straight or curve with the traffic lane. It is important that overlaps not be in the wheel paths nor exceed 75 mm (3 in.) in width.
- **Transverse Joints:** Transverse joints are inevitable when working with truck-mounted batch systems; every time a truck is emptied a transverse joint is required. Transitions at these joints must be smooth to avoid creating a bump in the surface. The joints must be butted to avoid these bumps and handwork be kept to a minimum. The main difficulty in obtaining a smooth joint occurs as the microsurfacing machine starts up at the joint, particularly when working with microsurfacing that is difficult to work by hand and breaks quickly. Some contractors tend to over wet (add too much water) the mix at start-ups, leading to poor texture and scarring at the joints. Starting transverse joints on roofing felt can eliminate these problems.
- **Edges and Shoulders:** Sealed edges and shoulders can be rough and look poor. This occurs more often with microsurfacing applications that break quickly, making them harder to work by hand than slurry seals. For microsurfacing, it is important that handwork be kept to a minimum. It is important that the edge of the spreader box be outside the line of the pavement and edge boxes be used when shoulders are covered.
- **Uneven Mixes and Segregation:** Poorly designed microsurfacing mixtures or mixtures with low cement content or too high a water content may separate once mixing in the box has ceased. This leads to a black and flush looking surface with poor texture. Separated mixes may lead to "false slurry," where the emulsion breaks onto the fine material. In such instances delamination may occur, resulting in premature failure. These types of mixes can be recognized as nonuniform and appear to set very slowly.
- **Smoothness Problems:** Microsurfacing mixtures follow the existing road surface profile and thus do not have the ability to significantly change the pavement's smoothness. However, when using stiffer mixes, the spreader box may, if incorrectly set up, chatter or bump as the material is spread and produce a washboard effect. The chattering may be reduced by making the mixture slower to set, adjusting the rubbers on the box, or adding weight to the back of the spreader box.
- **Damage Caused by Premature Reopening to Traffic:** It is important that the microsurfacing build sufficient cohesion to resist abrasion resulting from traffic. Early stone shedding is normal, but not to exceed 3%. If a mixture is reopened to traffic too early it will ravel off quickly, particularly in high stress areas. It is important that the mixture develops adequate cohesion before it is opened. Choosing the right time to reopen a surface to traffic is based largely on experience. However, a general

rule of thumb for a microsurfacing is that it can carry traffic when it is expelling clear water (National Highway Institute 2007).

- **Streaking:** Streaking is caused by one of two conditions during construction. Insufficient embedment allows larger stones to be caught by the strike-off rubber and dragged along the surface. Excess build-up of material in the spreader box has the same effect (ISSA 2010a).
- **Delaminating:** The major cause of delamination is failure to properly prepare the surface before commencing microsurfacing. It can also be caused by the emulsion breaking too fast, keeping the bond with the substrate from forming (Smith and Beatty 1999; Austroads 2003b).

Example Microsurfacing Quality Assurance Specification

The Georgia DOT microsurfacing specification (2001) includes a section specifically titled "workmanship" that speaks to the concerns discussed earlier and makes them enforceable contract requirements. The specification is included here as an example of how to articulate these concerns in the contract.

> **Workmanship**—Excessive buildup, uncovered areas, or unsightly appearance are not permitted on longitudinal or transverse joints. Place longitudinal joints on lane lines. Excessive overlap is not permitted. Ensure straight lines along the roadway centerline, lane lines, shoulder, or edge lines. Keep lines at intersections straight to provide a neat and uniform appearance.
>
> 1. **Finished Surface:** Ensure that the finished micro-surfacing has a uniform texture free of excessive scratch marks, tears, or other surface irregularities. Excessive tear marks are considered 4 marks that are ½ inch (13 mm) wide or wider and 6 inches (150 mm) or more long per 100 square yards (85 meters), or any marks 1 inch (25 mm) wide or wider or 4 inches (100 mm) long. Ensure that the edges of the micro-surfacing appear neat and that longitudinal alignment is parallel to the roadway centerline.
> 2. **Joints and Seams:** Produce neat and uniform longitudinal and transverse joints. Construct transverse joints as butt-type joints. Place longitudinal joints on lane lines when possible. Do not allow gaps between applications. Joints are acceptable if there is no more than a ½ inch (13 mm) vertical space for longitudinal joints nor more than ¼ inch (6 mm) for a transverse joint between the pavement surface and a 4 ft (1.2 m) straightedge placed perpendicular on the joint.
> 3. **Areas the Mixing Machine Cannot Reach:** Surface these areas using hand tools to provide complete and uniform coverage. Clean and lightly dampen the area to be hand-worked before placing the mix. Ensure areas that require handwork produce a finished surface that is uniform in texture, dense, and has a neat appearance similar to that produced by the spreader box. Microsurfacing material required to repair deficiencies due to unsatisfactory workmanship and the work required to mix and place the materials according to the Specifications will be provided at no expense to the Department (Georgia DOT 2001).

This discussion shows agreement between the literature and the specification content analysis and leads to the following effective practice:

Holding a pre-paving meeting to discuss quality management and workmanship issues before full production microsurfacing provides a forum where both the agency and the contractor can address main areas and concerns about microsurfacing quality.

MICROSURFACING PERFORMANCE

The purpose of any quality management program is to not only ensure that the product meets the contract requirements but also to ensure that the product is constructed in a manner that permits it to perform as designed. Therefore, connecting the quality management practice discussed previously with agency information about microsurfacing performance allows the analyst to draw inferences about the effectiveness of different approaches to this critically important topic.

Definition of Microsurfacing Success

Just as the term "quality" has many different definitions that depend on who and what it is related to, agency definitions of microsurfacing performance vary among the agencies themselves. The survey sought to draw out those answers and aggregate them to develop a rank ordering of 5+ standard definitions from the literature to identify any trends that might be present in the data. Table 35 shows the results of that analysis, with an interesting trend evident. In chapter three, the reasons why agencies select microsurfacing for a given pavement maintenance/preservation project were covered and a number of agencies added the comment that their purpose for using microsurfacing was to *extend the life* of the underlying pavement. This

TABLE 35
SUMMARY OF AGENCY DEFINITIONS OF MICROSURFACING SUCCESS

Test	U.S.	Canada	Total
Meets expected service life	19	6	25
Meets project specification requirements	14	6	20
Qualitative measures—look, color, etc.	8	8	16
Does not fail shortly after construction	7	5	12
Achieves desired friction/skid number	9	1	10
Meets texture standard (>0.6 mm)	1	0	1
No maintenance expenditures over life	1	0	1

Note: Agencies were asked to check all that applied.

attitude is validated by the most frequently cited success metric; meets expected microsurfacing service life. That leads to the conclusion that microsurfacing is viewed as a valuable pavement preservation treatment rather than merely a pavement maintenance treatment. The second most cited success metric was that the treatment met project specifications. This probably relates more to administrative process for contract payment than the long-term quality of the microsurfacing itself.

Post-construction visual assessment was the third most common success metric followed by the absence of short-term failure. The friction and texture metrics are the only two post-construction metrics that can be physically measured. The performance-based pavement maintenance contracts in use in New Zealand have as many as 200 post-construction performance criteria (Manion and Tighe 2007), many of which involve direct measurements of the pavement's surface characteristics. This explains why the Austroads respondents did not check qualitative measures as part of their success definition and leads to identification of an area for future research: evaluating engineering measurements used by Austroads (2003b) as acceptance tests for microsurfacing projects.

Minimizing Post-Construction Microsurfacing Defects

The survey also asked respondents to share the types of distresses that they most often found in their microsurfacing projects. Table 36 shows the results of that analysis. One can see that the most common distress found in microsurfacing was reflected cracking. This confirms the conclusion drawn in chapter three that microsurfacing is not effective in treating serious cracking. The second most common distress was streaking and it is directly related to the quality of the workmanship.

Raveling and delamination are the next two most common distresses in microsurfacing. Raveling can be caused by a number of material, design, or construction quality issues. A list of the most common is as follows:

- The aggregate lacks sufficient embedment in the matrix caused from insufficient asphalt quantity to hold the larger aggregate,
- Poor quality aggregates may debond from the matrix,
- The application rate was too thin to hold larger aggregates,
- The matrix has a lack of fines to fill voids between larger aggregates,
- Cooler temperatures may result in slowing of the cure necessary for traffic,
- Premature opening to traffic, and
- Rain fell on the microsurfacing prior to complete setting (ISSA 2010a).

Delamination is almost always the result of improper preparation of the substrate surface before microsurfacing (Smith and Beatty 1999; Austroads 2003a; ISSA 2010a). It can also be caused by the emulsion breaking too quickly, which results in a broken mix being placed on the surface that will not form a bond (Austroads 2003b). Finally, improper transverse and longitudinal joints were also cited as post-construction microsurfacing defects. Both of these are workmanship issues. The ISSA manual describes the cause as follows:

- **Transverse:** The transverse joint was constructed without using roofing felt, metal strips, etc., at the start of the placement pass. Similarly, the spreader box was either pulled until empty or ended without stopping on roofing felt or other protective surface meant to ensure a straight transverse joint. Poor joint construction practices result in excessive material build-up, uncovered areas, and unsightly appearance. Although proper joint construction techniques are followed, occasionally the mixture may not be performing as designed owing to changing environmental conditions (ISSA 2010a).
- **Longitudinal:** The placement machine may *not* have driving controls on both sides of the equipment so that the operator can follow existing edge markings, string lines, and previously placed microsurfacing in adjacent lanes. Many times the problem is related to poor planning of the product application process by the contractor. Excessive buildup, uncovered areas, or unsightly appearance often results from poor alignment of the longitudinal joint (ISSA 2010a).

The survey also asked the agency respondents to rate eight preconstruction factors on their ability to minimize these defects. The results of that analysis are shown in Table 37. It can be seen that the two different population groups

TABLE 36
SUMMARY OF COMMON MICROSURFACING POST-CONSTRUCTION DISTRESS

Distress	U.S.	Canada	Total
Crack Reflection	15	5	20
Streaking	9	2	11
Raveling	6	4	10
Delamination	7	1	8
Transverse Joints	5	3	8
Bleeding	4	1	5
Longitudinal Joints	4	0	4
Corrugation	1	1	2

Note: Agencies were asked to check all that applied.

TABLE 37
IMPACT OF PROJECT FACTORS ON MICROSURFACING QUALITY

Rated Impact (1 = highest rated factor)	U.S. Ranking	Canadian Ranking
Contractor Experience	1	2
Selecting the Right Project	2	1
Construction Procedure	3	3
Preconstruction Road Preparation	4	7
Better Aggregates	5	5
Better Binder	6	6
Design Method	7	4
QC/QA Program	8	8

TABLE 38
REASONS FOR MICROSURFACING FAILURE

Cause of Failure	U.S.	Canada	Total
Improper application rate	5	5	10
Dirty or dusty aggregate/gradation issues	4	4	8
Wrong road—poor project selection	6	2	8
Improper ambient and/or surface temperatures	3	3	6
Improper binder viscosity	3	3	6
Improper binder temperature	3	3	6
Improper surface preparation	3	2	5
Weather	2	2	4
Field construction procedures	1	0	1
Snow plow damage	1	0	1

cited the same top three factors: contractor experience, proper project selection, and construction procedures. Coupling contractor experience as having the most impact on quality with the finding in chapter four that the availability of qualified microsurfacing contractors was a major concern leads to the conclusion that a certification program for microsurfacing contractors is not only necessary, but it is also an urgent initiative.

This analysis also indicates that project selection is probably the most important step in the microsurfacing design process with regard to impact on the final performance of the microsurfacing itself. Finally, the relative importance of the material quality, design method, and QC/QA program indicates that the primary focus of the microsurfacing quality management program needs to be on workmanship rather than materials. By definition, microsurfacing is designed to incorporate high-quality materials (Johnson et al. 2007; ISSA 2010a). Thus, ensuring that the high-quality material is properly installed leads to the following effective practice:

> *Focus agency construction quality assurance efforts on those microsurfacing factors that relate to the quality of the workmanship and other field-related aspects.*

Microsurfacing Failures

Despite the best efforts of quality-conscious contractors and agency inspectors, microsurfacing projects do experience failures. The survey sought to gauge the magnitude and reasons for failures in microsurfacing projects. Table 38 shows the results of those data collection efforts. A trend in the failures is evident. The top reason for failure cited was using an improper application rate. The application rates are developed as part of the job mix formula development process, but need to be adjusted in the field. Assuming that the majority of the time the contractor is furnishing the job mix formula and has control over the application rates in the field, this failure is the contractors' responsibility. This information further validates the concern expressed in the previous paragraph with the need for qualified and experienced microsurfacing contractors to promote successful microsurfacing projects.

The aggregate issues cited in the table could be a function of doing gradation testing at the source (see Table 33). The aggregate will be handled several more times after it leaves the pit and research has shown that every time an aggregate is handled its gradation changes as the handling of the material creates more fines. Although it cannot be determined from this study, a possible fix would be to sample the aggregate gradation as close to its introduction into the mixing machine as possible. Thus, an aggregate that is of marginal quality in terms of soundness and abrasion resistance would be tested in the final gradation that is incorporated into the microsurfacing fix. Finally, project selection comes up once more as a reason for microsurfacing failure, underscoring the importance of that step in the design process.

The survey also sampled agency experience regarding complaints from the traveling public and their source. Table 39 contains the results. It is gratifying to see that the most common answer was "we don't get complaints." That statistic speaks volumes about the ability of microsurfacing to satisfy the needs of the traveling public for a safe, comfortable surface upon which to drive. Road noise and appearance were the next most common public complaints. Both of these are perceptional and were discussed in chapter three.

Microsurfacing Service Life

Finally, the survey asked the respondents to indicate what factor was most critical to microsurfacing achieving its intended service life (Table 40). The overwhelming answer from both groups was essentially selecting the right project for this

TABLE 39
PUBLIC COMPLAINT SUMMARY

Public Complaints	U.S.	Canada	Total
No Complaints	5	3	8
Road Noise	8	1	9
Appearance	5	3	8
Loose Stone	1	1	2
Vehicle Ride	1	0	1
Do Not Know	8	0	8

TABLE 40
SUMMARY OF SERVICE LIFE FACTORS

Service Life Factors	U.S.	Canada	Total
Underlying Pavement Structure	14	6	20
Original Substrate Surface Quality	12	4	16
Traffic Volume	5	0	5
Cold Climate Considerations (freeze/thaw cycles, snowplowing, etc.)	5	2	7
Maintenance Funding	2	1	3
Friction Loss	3	0	3
Construction Quality	0	1	1
Do Not Know	2	0	2

treatment's characteristics. Thus, training in this specific area is vitally important.

SUMMARY

This chapter reviewed the primary issues associated with microsurfacing construction quality. As a result of the analysis one effective practice, the pre-paving quality meeting, and one area for future research, were derived. The notion that "putting the right treatment on the right road at the right time" (Galehouse et al. 2003) was validated by this analysis of quality management practices. This confirms the idea that agencies that are considering microsurfacing need to invest the appropriate amount of time during the maintenance project programming process to ensure that those roads selected to receive microsurfacing are indeed good candidates for this treatment.

Conclusions

The following conclusions were reached in this chapter:

1. Microsurfacing is viewed as a valuable pavement preservation treatment rather than merely a pavement maintenance treatment.
2. Contractor experience was cited as the most important factor affecting microsurfacing quality. With this identified need for competent contractors, a microsurfacing certification program would furnish a means to identify competent microsurfacing contractors.
3. Project selection is probably the most important step in the microsurfacing design process with regard to impact on the final performance of the microsurfacing itself.

Effective Practices

The following effective practices were identified in this chapter:

1. Holding a pre-paving meeting to discuss quality management and workmanship issues before full production microsurfacing provides a forum where both the agency and the contractor can address main areas and concerns about microsurfacing quality.
2. Focusing agency construction quality assurance efforts on those microsurfacing factors that relate to the quality of the workmanship and other field-related aspects.

CHAPTER EIGHT

CASE STUDIES

INTRODUCTION

As with most pavement preservation tools, microsurfacing has many uses and those uses differ from agency to agency based on individual experiences, climatic conditions, and traffic volumes. The previous chapters have chronicled the very aspects of microsurfacing from a general practice level. This chapter will review six case studies. Each was selected because it detailed a specific aspect of microsurfacing's state of the practice. Kohn (1997) posits that case study research can be used for the following reasons:

- To *explore* new areas and issues where little theory is available or measurement is unclear;
- To *describe* a process or the effects of an event or an intervention, especially when such events affect many different parties; and
- To *explain* a complex phenomenon.

Microsurfacing is the domain of specialty contractors who not only install the product but, as shown in chapter three, also furnish the technical design for their product. This puts the agency at a *disadvantage in terms of theoretical knowledge and experience.* The survey found that fully one-fourth of the agency respondents did not even use microsurfacing, making it *a new area* for those entities. Pavement maintenance and preservation is by definition *an intervention* whose process needs to be *clearly described* to ensure that it is properly utilized and its inherent benefits are accrued by the owner agency. Finally, chapter three shows it to be a complex phenomenon that needs to be explained so that its desirable qualities can be properly exploited for pavement maintenance and preservation programs. Hence, all three of these reasons apply to this synthesis report, making the case studies particularly valuable to this type of study.

CASE STUDY DESCRIPTIONS

Table 41 summarizes the case study programs that will follow this section. Scanning the table will show that the cases were drawn from agencies across the United States and in Canada. They also encompass both warm southern climates and cold northern climates where snowplowing impacts microsurfacing performance. Each was selected to demonstrate a specific aspect of microsurfacing practice. The case studies were drawn from the literature and fleshed out with telephonic or face-to-face interviews where necessary to ensure an accurate interpretation of the information contained in the literature. Each case will be briefly described and then the analysis' focus will shift to specific lessons learned. Finally, the results of the case study will be compared with the information derived from the other study instruments to generate conclusions and effective practices.

Microsurfacing as Pavement Preservation—Maine Department of Transportation

This case study consisted of a 5-year field test of microsurfacing placed on asphalt pavements on two highways in northern Maine. The test compared microsurfacing with thin (1.7 in. or 43 mm) hot-mix asphalt (HMA) overlays. The objective of the trials was to evaluate microsurfacing's ability to "extend the service life of two projects" (Marquis 2009). Table 42 contains the salient facts about the project.

Results of the Maine Case Study

This 5-year field evaluation found that microsurfaced sections showed considerably more wear than the HMA overlay sections. The details are as follows:

- Most high spots of the microsurfaced roadway have been abraded by winter snow removal equipment. In some areas the microsurfaced treatment has been worn away completely.
- Microsurfacing has higher IRI [International Roughness Index] values and Frictional Resistance is slightly higher than the HMA sections.
- Microsurfacing appeared to slow the progression of reflective cracking up [for 2 years] . . . [then] cracks reflected through the microsurfaced sections at a higher rate than the HMA sections.
- Microsurface treatments claim to add between five and seven years life to existing pavements. This appears to be the case on the Limestone project where the material is performing as expected. The only apparent issue is snow plow abrasion (Marquis 2009).

Lessons Learned

A full analysis of the three reports available in this case study (Marquis 2002, 2004, 2009) provides two lessons learned. The

TABLE 41
CASE STUDY PROGRAM SUMMARY

Case Study	Agency/Location	Reason for Inclusion	Remarks
Microsurfacing as a pavement preservation treatment	Maine DOT Caribou, Maine	Specific use for pavement preservation; long-term performance in an area with heavy snowplowing	Demonstrates microsurfacing performance in cold, snowy climate; answers concerns that it is not appropriate on roads with heavy snowplowing
Use of microsurfacing as a preventive maintenance treatment to improve safety	York Region Ontario, Canada	Focus on safety; specific use for preventive maintenance	Demonstrates a use for microsurfacing that does not focus on pavement distress
Long-term comparative performance of microsurfacing on asphalt and concrete pavements	Oklahoma DOT Tulsa and Oklahoma City, Oklahoma	Used for filling deep ruts and treating alligator cracking on high-volume interstate; 9-year record	Very comprehensive look at the treatment in a variety of situations
Microsurfacing on a high traffic interstate highway	Georgia DOT Atlanta, Georgia	Heavy urban traffic volume; road noise evaluation	Agency survey response indicated they do not use microsurfacing
Microsurfacing on Jointed plain concrete pavement	Kansas DOT Cowley County, Kansas	Evaluation of ride quality improvement; use of microsurfacing on a concrete surface	Ride quality is of prime importance on concrete pavements; comparison is with a hot-mix overlay
Microsurfacing using a softer binder	Minnesota DOT Albertville, Minnesota	Evaluation of cracking and rut filling performance	Provides an alternative for situations where cracking is the primary issue

first lesson regards the impact of snowplowing on microsurfacing. Both microsurfacing sections were visibly abraded by snow removal equipment. The report states: “Most high spots of the microsurfaced roadway have been abraded by winter snow removal equipment.” Given this premise, the three performance measures studied (International Roughness Index, rut depth, and friction number) were all within acceptable limits for the Limestone road [1,100 average annual daily traffic (AADT)] and only rut depth was unacceptable on the Presque Isle (8,600 AADT). Thus, the following lesson learned can be noted:

Snowplowing will abrade microsurfacing and eventually wear it away. Although this is an issue if the treatment is used to act as a seal to water intrusion it does not significantly impact the use of microsurfacing to enhance ride

TABLE 42
MAINE DOT CASE STUDY FACTS

Item	Data
Binder	CSS-1H
Aggregate	Type III
Mineral Filler	Non-air entrained portland cement
Job Mix Design	
Aggregate	100%
Portland cement	1.0%
Water	10.0%
Binder	12.0% ± 1%
Test Specification	
Residual asphalt	8.3
Wet track abrasion—1 h	470.0
Wet track abrasion—6 day	680.0
Excess asphalt loaded wheel	453.2
Wet stripping	96.0
Compatibility	11 pts
Location	Route 1 between Presque Isle and Caribou, Maine Route 1A between Limestone and Caswell, Maine
ADT	8,600 and 1,100, respectively
Distress Level Before Microsurfacing	
IRI (*m/km*)	0.97 to 2.14 (62 to 136 in./mile)
Rut depth (*mm*)	9.95 to 12.75 (0.39 to 0.50 in.)
Friction number	Average 53.2
Length of Test Period	5 years
Snowplowing?	Yes

ADT = average daily traffic.

quality and skid resistance or as a rut filling technique on a structurally sound pavement.

The second lesson in this case deals with skid resistance. Both the Presque Isle and Limestone microsurfaced test sections were found to furnish higher skid numbers throughout the 5-year test period than the HMA test sections on the same roads. The higher volume road lost 3.4% and the lower volume road lost 1.1% over the period. Therefore, the lesson learned is:

Using microsurfacing to correct the loss of frictional resistance on a structurally sound pavement works well in a Northern climate.

Effective Practices

One effective practice can be derived from this case study. The analysis of the literature review shown in Table 7 (chapter three) found that among those authors that specifically mentioned snowplowing that microsurfacing was found to be suitable for use in those areas more often than it was cited as a concern (four positive versus one negative citations). Next, the survey received responses from 23 states where winter snow removal is an issue and only 6 did not include microsurfacing in their pavement maintenance programs. Additionally, all of the Canadian provinces except one use microsurfacing. Therefore, the intersection of those two lines of information with the one contained in this case study yields the following effective practice:

Microsurfacing can be effectively employed on roads where routine winter snow removal is a factor if the underlying pavement is structurally sound.

Microsurfacing as Preventive Maintenance—York Region

This case study consisted of the analysis of microsurfacing's impact on safety when used as a preventive maintenance tool to restore skid resistance. The study evaluated accident rates over a 4-year period of microsurfacing placed on pavements on two highways in the Region of York in Ontario, Canada. The test compared 28 microsurfacing sites with 12 HMA overlays. The objective of the study was to evaluate the inclusion of safety issues in an agency's preventive maintenance program (Erwin and Tighe 2008). It used the two types of pavement surface treatments and an accident rate before and after to test the study's hypothesis. Table 43 contains the salient facts about the project.

Results of the York Case Study

Figure 26 is a map that shows the location of the York Region in the Canadian Province of Ontario. The results of the study are summarized as follows:

- Microsurfacing has a positive safety effect when applied at locations with an AADT greater than 3,000 vehicles per lane.
- Microsurfacing has been demonstrated to have a positive safety effect on locations with higher traffic volumes susceptible to any one or combination of these conditions:
  – occurrence of wet or slick (not dry) road surface conditions;
  – trend in severe crashes;
  – frequent intersection-related crashes; and
  – high occurrence of rear-end crashes.
- Another point to consider is that contractors [furnish lower] treatment prices for larger jobs. To capitalize on that opportunity and keeping in mind that microsurfacing was demonstrated to be very effective at reducing intersection-related crashes, when

TABLE 43
YORK REGION CASE STUDY FACTS

Item	Data
Binder	CSS-1h
Aggregate	Type III
Mineral Filler	Non-air entrained portland cement
Job Mix Design—Typical	
Aggregate	100%
Portland cement	2.0%
Water	10.0%
Binder	11.5% ± 1%
Test Specification—Typical	
Residual asphalt	6.0% to 11.5%
Wet track abrasion—1 h	538.0
Wet track abrasion—6 day	807.0
Excess asphalt loaded wheel	538.0
Wet stripping	90.0
Compatibility	11 pts
Location	28 sites through the Region of York
AADT	1,000 to 7,000+
Distress Level Before Microsurfacing	
IRI (m/km)	Not available
Rut depth (mm)	Not available
Friction number	Not available
Length of Test Period	4 years
Snowplowing?	Yes

AADT = average annual daily traffic.

FIGURE 26 Map of the York region case study.

prioritizing treatment sites; one could group intersection to and tender them out as single job. Such foresight in the planning process can help agencies stretch their budgets farther while making the roads safer.

Lessons Learned

Two lessons can be drawn from this case study. First, the idea of including safety in a public highway agency's pavement maintenance/preservation program is appropriate. A structurally sound pavement could be rendered unsafe merely to loss of skid resistance resulting from the polishing of the pavement's aggregate (Gransberg 2009). The literature shows that countries with a tradition of performance-based pavement maintenance contracting such as Australia and New Zealand include accident rates as a key performance indicator (Gransberg et al. 2010). Therefore, adding an analysis of accident rates to the pavement maintenance/preservation project selection process makes sense. The lesson learned here is as follows:

Because microsurfacing has shown itself to be particularly effective in reducing intersection accidents, adding safety issues to the project-specific treatment selection process may furnish added value to an agency's pavement maintenance/preservation program.

The second lesson learned is that it would be beneficial to use microsurfacing in localized areas that are expected to experience frequent stopping. For instance, freeway ramps would benefit from a higher friction surface to enhance emergency stopping during unexpected situations. Thus, the lesson learned is:

Microsurfacing can be effectively used to enhance skid resistance in areas where a reduction in stopping distance is critical to safe operation of a given highway feature.

This approach has not been developed enough to yield an effective practice. It does intersect with the literature, but the survey responses reflected that using it to improve friction is not currently a primary reason for selecting microsurfacing for a given project.

Long-Term Evaluation of Microsurfacing Performance—Oklahoma Department of Transportation

This case study reports on an early large-scale field test of microsurfacing used to fill deep ruts and alligator cracking on high-volume four-lane divided highways in Oklahoma. The three sites studies were located in Oklahoma City and Tulsa. The study lasted 9 years and yielded valuable information that the Oklahoma DOT used to modify its microsurfacing program. That the Oklahoma DOT still uses microsurfacing as a major tool in its pavement maintenance and preservation program amply demonstrates the value of including the case study in this synthesis. Table 44 contains the important data about this case. Table 45 shows the aggregate gradations used by the DOT specifically for deep rut filling and alligator cracking compared with the standard microsurfacing gradation.

Results of the Oklahoma DOT Case Study

The major findings of this robust study are as follows:

- Microsurfacing reduces the level of rutting and retards the rate of rutting for up to four years of service.
- Microsurfacing provides good friction characteristics for up to nine years of service.
- Microsurfacing can be used effectively to fill ruts up to 38 mm (1.5 inch) deep.
- Microsurfacing works well for filling depression cracks and alligator cracks.
- Microsurfacing worked successfully with mine chat (cherty limestone) and dolomite/granite aggregate mixture (Hixon and Ooten 1993).

Lessons Learned

Two lessons learned can be derived from this case. The first regards the sustainability of microsurfacing and the ability to increase its "greenness" by utilizing recycled waste materials such as mine chat. Not only does microsurfacing require less bituminous material, because it is cold-laid it consumes less energy than other treatment alternatives. Therefore, the lesson learned in this case is as follows:

Microsurfacing is a "green" alternative and can be used to promote sustainable maintenance practices by using recycled waste products such as mine chat for aggregate and products such as fly ash and cement kiln dust as mineral filler.

The second lesson learned comes from the special aggregate gradations used by the Oklahoma DOT. The literature contradicts the Oklahoma experience with regard to alligator cracking as can be seen in Table 9. However, because the Oklahoma DOT used a special gradation designed specifically

TABLE 44
OKLAHOMA DOT CASE STUDY FACTS

Item	Data
Binder	CSS-1h
Aggregate	See Table 45
Mineral filler	Non-air entrained portland cement
Job Mix Design—Typical	
Aggregate	90%
Portland cement	2.0%
Water	9.0%
Binder	9% ± 1%
Test Specification—Typical	
Residual asphalt	8.0% to 13.0%
Wet track abrasion—1 h	Not available
Wet track abrasion—6 day	Not available
Excess asphalt loaded wheel	Not available
Wet stripping	Not available
Compatibility	Not available
Location	I-40 in Oklahoma City: 2 sites US-64 in Tulsa: 1 site
AADT	11,000 to 40,000
Distress Level Before Microsurfacing	
IRI (*m/km*)	Not available
Rut depth (*mm*)	72 to 81 mm (2.8 to 3.2 in.)
Friction number	32–44
Length of Test Period	9 years
Snowplowing?	No

AADT = average annual daily traffic.

to treat alligator cracking, the two lines of information are not directly comparable. Thus, it appears that a one-size-fits-all approach to microsurfacing design may optimize microsurfacing's rut filling ability at the expense of its crack filling ability. This idea is validated because the Oklahoma DOT used a special gradation for filling deep ruts rather than the "normal" gradation. Therefore, the lesson learned is:

> *The aggregate gradation in the job mix design is to be customized to match the primary purpose of utilizing microsurfacing on a given road with specific gradations being developed for cracking versus rut filling.*

Effective Practices

Taking the findings in this case study regarding microsurfacing's ability to furnish long-term surface friction characteristics and intersecting it with the information found in the York case study and the literature, the following effective practice is proposed:

> *Microsurfacing is the proper alternative to enhance skid resistance in areas where the frictional characteristics of the road's surface are to be restored to safe operating limits.*

Microsurfacing on High-volume Roads—Georgia Department of Transportation

This case study (Tables 46 and 47) consisted of an experimental trial of microsurfacing to address wheel path raveling and cracking on 92 lane-kilometers of Interstate 285 in Atlanta. Because the motivation for the project was part of the preparation for the 1996 Summer Olympics, aesthetics was also a consideration. The project used both a tack coat and a scratch course. The Georgia DOT evaluated friction, crack propagation, and road noise.

TABLE 45
OKLAHOMA DOT CASE STUDY AGGREGATE GRADATIONS

	Percentage Passing		
Sieve Size	ODOT-Type I (alligator cracking)	ODOT-Type II (normal)	ODOT-Type III (deep ruts)
3/8 (9.5 mm)	100	99–100	98–100
#4 (4.75 mm)	98–100	80–94	75–85
#10 (2.36 mm)	68–86	44–60	45–55
#40 (420 μm)	22–41	12–30	15–25
#80 (177 μm)	10–25	8–20	8–25
#200 (75 μm)	5–15	5–15	2–8

Source: Hixon and Ooten (1993).

TABLE 46
GEORGIA DOT CASE STUDY FACTS

Item	Data
Binder	CSS-1HLM (Ralumac with 3% natural latex)
Aggregate	See Table 47
Mineral filler	Type I portland cement
Job Mix Design—Typical	
Aggregate	100%
Portland cement	1.0%
Water	10.0%
Binder	7.4%
Test Specification—Typical	
Residual asphalt	6.8%
Wet track abrasion—1 h	807
Wet track abrasion–6 day	538
Excess asphalt loaded wheel	538
Wet stripping	90%
Compatibility	Pass
Location	I-285 in Atlanta, Georgia
AADT	55,650
Distress Level Before Microsurfacing	
IRI (*m/km*)	0.573 (36.1 in./mile)
Rut depth (*mm*)	19 mm (0.75 in.)
Friction number	46–50
Length of Test Period	2 years
Snowplowing?	no

AADT = average annual daily traffic.

TABLE 47
GEORGIA DOT CASE STUDY
AGGREGATE GRADATION

Sieve Size	Percentage Passing GDOT
3/8 (9.5 mm)	100
#4 (4.75 mm)	80
#8 (2.36 mm)	68–86
#50 (300 μm)	22–41
#200 (75 μm)	5–15

Results of the Georgia DOT Case Study

The Georgia DOT case study is summarized as follows:

- The microsurfacing used on I-285 has performed quite well.
- No additional problems with raveling or load cracking have been encountered.
- The mix has provided excellent smoothness and good friction, with a minimal increase in pavement noise levels.
- It is aesthetically superior to slurry seal because of its resemblance to hot-mix asphalt (Watson and Jared 1998).

The unique feature of this study was the comparison of noise levels with other surface courses. Table 48 provides the comparison with several locations in the Atlanta metro area. It shows that the change is virtually negligible. When this is compared with the survey results where the respondents cited road noise as the most frequent public complaint about microsurfacing a dichotomy exists. One possible explanation is that public road noise complaints are the result of the differential change from the original surface, which may have seemed quieter owing to low friction characteristics, and the microsurfacing that increased the texture of the wheel paths.

Lessons Learned

The major lesson from this case study deals with the qualitative aspects of microsurfacing and its use as a "quick fix" to enhance the appearance of a road at a low cost while extending its life and enhancing the safety of the traveling public by

TABLE 48
COMPARISON OF MICROSURFACING ROAD NOISE TO
OTHER COMMON SURFACES

Surface Course	Average Decibels	Microsurfacing Difference
Microsurfacing	74.9	—
Conventional OGFC	73.9	+1.0
Modified OGFC	72.8	+2.1
Porous European Mix	72.7	+2.2
Dense Graded Surface Mix	73.1	+1.8
Portland Cement Concrete	73.1	+1.8

Source: Watson and Jared (1998).
OGFC = open-graded friction course.

increasing friction numbers. This speaks to the public relations aspects that impact public highway agencies. It also demonstrated that road noise complaints are largely perceptional and that the public can be educated by showing them the numbers such as the Georgia DOT did. Thus, this lesson can be stated as follows:

> *Microsurfacing can be used as a cost-effective means to enhance the visual quality of a high-volume road while simultaneously enhancing skid resistance, smoothness, and addressing raveling and cracking issues on a high-volume highway.*

This case study did not yield any effective practices.

Microsurfacing Performance on Concrete Pavement—Kansas Department of Transportation

The objective of this case study was to test microsurfacing's ability to improve ride quality on a jointed, plain concrete pavement on US-77 in Cowley County, Kansas. Kansas DOT engineers investigated a number of alternatives (diamond grinding, HMA overlay, and cracking and sealing) and selected microsurfacing based on cost and time required for installation. The concrete pavement was structurally sound, although the ride was rough owing to joints that were faulted approximately 6 mm (0.25 in.). Before installation, the joints and cracks in the substrate were sealed and a tack coat consisting of SS-1h emulsion was applied. Tables 49 and 50 contain the details of this case.

Results of the Kansas DOT Case Study

The results of the Kansas DOT case study project in Cowley County, Kansas, can be summarized as follows:

- A relatively thin application of microsurfacing (20.6 kg/m^2) placed in two lifts improved the ride quality of JPCP [jointed plain concrete pavement].
- The contractor was able to complete the 1.6 km (1 mile) test section including the sealing of joints and cracks in 10 working days.
- The ride quality improvement when a short-span, 2.4-m ski was attached to the paving box indicated a minor increase (16.7% on average) in smoothness from the original pavement.
- The use of a 4.9-m ski produced a marked improvement (49% on average) in smoothness from the original pavement.
- The average final profile index on the project for the 14.1-km (8.8-mi) section where the 4.9-m ski was used was 436 mm (27.48 in.), well within the limits established by Kansas DOT of 254 to 762 mm for a 100-mm-thick bituminous pavement (Moulthrop et al. 1996).

Lessons Learned

This case study project documents the successful enhancement of ride quality on jointed plain concrete pavement using microsurfacing. It was included because much of the nation's Inter-

TABLE 49
KANSAS DOT CASE STUDY FACTS

Item	Data
Binder	CSS-1HLM (Ralumac)
Aggregate	See Table 50
Mineral filler	Type I portland cement
Job Mix Design—Typical	
Aggregate	100%
Portland cement	1.75% ± 0.25%
Water	As required
Binder	7.6% ± 0.4%
Test Specification—Typical	
Residual asphalt	6.8%
Wet track abrasion—1 h	Not available
Wet track abrasion—6 day	Not available
Excess asphalt loaded wheel	Not available
Wet stripping	Not available
Compatibility	Pass
Location	US-77 in Cowley County, Kansas
AADT	4,000
Distress Level Before Microsurfacing	
IRI (m/km)	0.848 to 0.929 (52.6 to 57.6 in./mile)
Rut depth (mm)	Not applicable
Friction number	Not applicable
Length of Test Period	2 years
Snowplowing?	Yes

AADT = average annual daily traffic.

TABLE 50
KANSAS DOT CASE STUDY
AGGREGATE GRADATION

Sieve Size	Percentage Passing KDOT
3/8 (9.5 mm)	99–100
#4 (4.75 mm)	86–94
#8 (2.36 mm)	45–65
#16 (1.19 mm)	25–46
#30 (300 μm)	15–35
#50 (297 μm)	10–25
#200 (75 μm)	5–15

state Highway System was constructed using this pavement type, and ride roughness is a major issue on roads with this type of pavement. Often concrete pavements are found in urban areas where the high traffic volume initially warranted the higher construction cost and lower life-cycle costs that concrete furnishes. The cardinal outcome of the case was the finding that microsurfacing delivered a smoothness that was comparable to hot mix (Moulthrop et al. 1996). Thus, this case provides a valuable tool for pavement managers dealing with this issue. Two lessons learned can be derived from this case study project.

- *Microsurfacing furnishes a cost-effective means to improve ride quality on jointed concrete pavements; and*
- *Microsurfacing provides an expeditious means to improve ride quality while minimizing disruption to traffic.*

Effective Practices

In this case study, the standard microsurfacing equipment needed to be modified for use on jointed concrete pavement. A detailed explanation of the modifications is as follows:

> The standard load-bearing support for the laydown box consists of three steel skis, on which the box rides as it is pulled along the pavement. These skis are normally 1.8 m (6 ft) long at the outside support location and shorter at the middle of the box. For this project, the skis were initially changed to 2.4 m in length to help support the laydown box when it passed over the faulted joints. This did not produce the desired smoothness and, after consultation with the project engineers, it was decided that the box needed to have better support to stop it from tipping when the skis passed over the joints. The contractor fabricated a 4.9-m-long supported-beam leveling arm that attached solidly to the laydown box at the outside edge. This beam had attached at each end of it small metal skis that pivoted when the ski passed over the joints. The beam was attached to the laydown box so that the standard 1.8 m skis were left attached to the bottom of the box. The beam supported the box, which eliminated the tipping. The other equipment adjustment made to the standard laydown box configuration was the use of a steel (rigid) strikeoff plate instead of the rubber (flexible) strikeoff that is normally used. Usually a microsurfacing laydown box uses a rubber strikeoff to finish the surface. When a flexible strikeoff is used, downward pressure is applied to the fresh mix, which causes a small amount of deformation in the surface. Rubber tends to follow the natural surface contours, thus restricting the leveling. When a rigid strikeoff is used, it does not flex. This rigidity allows for better reprofiling of the pavement section (Moulthrop et al. 1996).

Therefore the following effective practice is found:

When using microsurfacing to improve ride quality on jointed plain concrete pavements, the spreader box can be modified to furnish better support across the joints and the flexible rubber strike-off can be replaced with a rigid strike-off to improve smoothness.

Microsurfacing Performance with a Softer Binder—Minnesota Department of Transportation

The objective of this case study was to test the impact of a softer binder on microsurfacing's ability to resist reflective cracking and act as a surface preparation measure for subsequent leveling or rut-filling courses. Minnesota DOT engineers investigated this treatment on four test sections originally paved in 1993. Before installation, cracks in the substrate were sealed in only one test section and a tack coat consisting of diluted CSS-1h emulsion was applied. Table 51 contains the details of this case.

Results of the Minnesota DOT Case Study

The results of the Minnesota DOT case study project at the Minnesota Test Road Facility can be summarized as follows:

- The construction phase demonstrated the viability of producing and placing microsurfacing slurry mixtures at 12.5% and 16.5% emulsion levels. Mixture consolidation did not appear problematic when very-low-volume traffic was involved.
- Following a 6-month service period that included a northern climate winter, the project was evaluated for reflective cracking, smoothness, and rutting. Approximately 71% of transverse cracks and 5% of longitudinal cracks had reflected through the microsurface.
  - Transverse cracks in lanes constructed with scratch and wear course mixtures had reflected through the microsurface to 88% of preconstruction numbers.
  - Transverse cracks in lanes constructed with rut-fill and wear course mixtures had reflected through the microsurface to 60% of preconstruction numbers.
  - Patched locations were not reflecting through the microsurface.
- Pavement IRI measurements showed little change from the post-construction condition. The 6-month IRI was found to have decreased by 22% for lanes constructed with scratch and wear course mixtures, and by 58% for lanes constructed with rut-fill and wear course mixtures.
- Rut conditions as measured after construction showed the following results:
  - A 4% to 6% decrease for lanes constructed with scratch and wear course mixtures,

TABLE 51
MINNESOTA DOT CASE STUDY FACTS

Item	Data
Binder	CSS-1 using PG 49-34 asphalt binder
Aggregate	Type II
Mineral filler	Type I portland cement
Job Mix Formula—Typical	
Aggregate	100%
Portland cement	1.75% $\pm$ 0.25%
Water	As required
Binder	12.5% and 16.5% $\pm$ 0.4%
Test Specification—Typical	
Residual asphalt	8% to 8.5%
Softening point	128°F
Penetration	163
Excess asphalt loaded wheel	Not available
Wet stripping	Not available
Compatibility	Pass
Location	Minnesota Road Test Facility Albertville, MN
AADT—Test road	80 truck passes per day
Distress Level Before Microsurfacing	
IRI (m/km)	1.24 to 3.25 (52.6 to 57.6 in./mile)
Rut depth (mm)	8 to 46 (0.33 to 1.81 in.)
Friction number	Not applicable
Length of Test Period	2 years
Snowplowing?	Yes

AADT = average annual daily traffic.

  - A 11% to 40% decrease for lanes constructed with rut-fill and wear course mixtures,
  - A 7% decrease for 102-kip load-configuration lanes, and
  - A 32% decrease for 80-kip load-configuration lanes.
- Early results from this research show that the soft asphalt concrete microsurface design has a moderate effect in decreasing transverse reflected cracks.
- Data . . . also suggest that the soft asphalt concrete microsurfacing is effective at reducing rutting (Johnson et al. 2007).

Lessons Learned

This case study project documents the results of using a softer asphalt binder in the microsurfacing JMF. Two lessons learned can be derived from this case study project.

- *Microsurfacing furnishes a promising means to reduce the amount of transverse reflective cracking; and*
- *The amount of binder can be successfully varied in the field to enhance microsurfacing ability to fill ruts.*

Effective Practices

This case study yielded the following effective practice.

The microsurfacing binder amount can be reduced by 1% to 2% in rut filling and scratch courses upon which a wearing course will be applied.

SUMMARY AND EFFECTIVE PRACTICES

This chapter presented six case studies that each demonstrated a particular aspect of microsurfacing practice. The case studies covered projects in both northern and southern climates, in the United States and Canada, on rural and urban highways, and on both asphalt and concrete pavements. In summary, the case studies highlighted the robust ability of microsurfacing to effectively address many common pavement distresses while enhancing skid resistance, ride quality, aesthetics, and extending the service lives of the pavements upon which they are placed. This chapter produced 16 lessons learned and 4 effective practices. The effective practices are as follows:

1. Microsurfacing can be effectively employed on roads where routine winter snow removal is a factor if the underlying pavement is structurally sound.
2. Microsurfacing is the proper alternative to enhance skid resistance in areas where the frictional characteristics of the road's surface are to be restored to safe operating limits.
3. When using microsurfacing to improve ride quality on jointed plain concrete pavements the spreader box can be modified to furnish better support across the joints and the flexible rubber strike-off would be replaced with a rigid strike-off.
4. The microsurfacing binder amount can be reduced by 1% to 2% in rut filling and scratch courses upon which a wearing course will be applied.

CHAPTER NINE

CONCLUSIONS

INTRODUCTION

Chapters one and two set the criteria used in this report for drawing conclusions and identifying effective practices. That process was followed rigorously throughout the entire report. The results are based on the four study instruments used to collect the information contained in the synthesis: a comprehensive literature review, survey of U.S. and Canadian agencies, microsurfacing specification content analysis, and case studies. When two or more independent lines of information from one of those four sources intersected, a conclusion was reached or an effective practice was proposed. Lastly, when a gap in the body of knowledge was revealed, a suggestion for future research was made. Therefore, based on that foundation, the conclusions, effective practices, and suggestions for future research are presented in this chapter.

CONCLUSIONS

The following conclusions were reached in the conduct of this study. They are not listed in any order of importance.

- Of all the standard microsurfacing specifications from 50 U.S. states plus the District of Columbia and the FHWA Federal Lands Highway Division, only 18 had sections that specifically contained the word "microsurfacing." As a result, there is a potential for confusion in the literature about the difference between microsurfacing and slurry seals, which spawns a potential for an inaccurate exchange of technical information on the two treatments.
- Only two agencies use microsurfacing on a regular preventive maintenance cycle and a number of survey respondents indicated that their agency uses microsurfacing to extend the life of the underlying pavement. That approach was validated by the majority of respondents, indicating that they use service life as their measure of treatment success. That leads to the conclusion that microsurfacing is viewed as a valuable pavement preservation treatment rather than merely a pavement maintenance treatment.
- Microsurfacing is best suited to address rutting, raveling, oxidation, bleeding, and loss of surface friction. Microsurfacing is not appropriate for structurally deficient pavements. This makes project selection the most important step in the microsurfacing design process with regard to impact on the final performance of the microsurfacing itself.
- Microsurfacing can be expected to provide an average service life of 7 years if the underlying road is in good condition.
- Microsurfacing is a pavement preservation and maintenance tool with very few technical or operational limitations.
  - Microsurfacing was shown to be effective for all levels of traffic, as well as useful in both urban and rural settings.
  - Microsurfacing was shown to be effective on both asphalt and concrete pavements.
  - Microsurfacing can be effectively used in locations where the work is to be done at night or in cool weather, as well as where stresses resulting from stopping and snow plowing are present.
- The majority of the respondents that use microsurfacing assign the contractor the responsibility for completing the job mix formula. That the majority of the same population rates their microsurfacing project performance as satisfactory indicates that contractor-furnished design does not degrade final quality.
- Microsurfacing can be procured using a performance-based contract. The content analysis found that a number of agencies are already using performance specifications in their microsurfacing contracts.
- Microsurfacing is one of the few pavement preservation and maintenance treatments that can restore the transverse geometry of a rutted road. Because U.S. agencies use it primarily as a surface course, they are not maximizing the potential benefits of microsurfacing when they do not use it as the primary tool to fill ruts as their Canadian counterparts do.
- Most agencies only use a single microsurfacing emulsion, and all agencies rated their microsurfacing performance as satisfactory. Therefore, an agency can select a single emulsion that works best for its specific climatic and traffic environment and achieve satisfactory results.
- The majority of maintenance practitioners do not consider environmental impact in their microsurfacing project development process.
- Most of the U.S. and Canadian agencies do not perceive that they have an adequate level of competition among qualified microsurfacing contractors for their programs. This may be because most microsurfacing programs do not advertise a consistent amount of work each year, making it difficult for interested contractors to develop the technical capacity and equipment necessary to competitively bid on these contracts.

- Most agencies do not prequalify microsurfacing bidders. This may be because the pool of competent and qualified contractors is inherently shallow. Contractor experience was also cited as the most important microsurfacing quality factor. Therefore, the FHWA's Pavement Preservation Expert Task Group initiative to develop a certification program at the national level is needed.
- Requiring warranties for microsurfacing projects is not problematic because the contractor normally furnishes the job mix formula.

EFFECTIVE PRACTICES

Effective practices are identified when the analyses found multiple instances of microsurfacing success when certain techniques or approaches were utilized in the design, contracting, or construction phase of a microsurfacing project. Additionally, the case study analysis identified a few other effective practices based on the detailed analysis found in those projects.

- Effective Practices in Microsurfacing Project Selection
  1. Project selection is critical to microsurfacing success and those agencies that only apply microsurfacing to structurally sound pavements are generally satisfied with its performance.
  2. Microsurfacing performs best when applied to correct surface friction, oxidation, raveling, and/or rutting on pavements that have adequate structural capacity.
- Effective Practices in Microsurfacing Design
  1. Microsurfacing design can be successfully assigned to the microsurfacing contractor with the agency reviewing and approving the final job mix formula.
  2. Compounds added to microsurfacing job mix formulas can be selected by the emulsion manufacturer and the agency can then verify that they are compatible with the approved job mix formula.
  3. Microsurfacing programs can be successfully implemented with a single binder type with a record of satisfactory performance in a given agency's climate and traffic conditions.
- Effective Practices in Microsurfacing Contracting
  1. Agencies in northern climates can mitigate potential quality issues induced by a short microsurfacing season by requiring a warranty.
  2. It is important that agencies in northern climates let microsurfacing projects as early as possible to permit their completion as early in the season as possible and mitigate the risk that unstable weather at the end of the season will adversely impact microsurfacing quality.
  3. Microsurfacing is to be paid for by the ton if the agency is not using a performance specification.
  4. Make microsurfacing contract packages as large as is practical to reduce the unit price and increase the number of lane-miles that can be treated each year.
- Effective Practices in Microsurfacing Construction
  1. When using microsurfacing to improve ride quality on jointed plain concrete pavements, the spreader box can be modified to furnish better support across the joints and the flexible rubber strike-off can be replaced with a rigid strike-off
  2. Requiring that a test strip of 500 to 1,000 ft (152.4 to 304.8 m) in length be constructed and inspected allows the agency and the contractor to ensure that microsurfacing equipment is properly calibrated and that any workmanship issues are resolved before full-scale microsurfacing production. If the microsurfacing is scheduled to occur after dark, it is important that the test strip be constructed after dark.
  3. Holding a pre-paving meeting to discuss quality management and workmanship issues before full production microsurfacing provides a forum where both the agency and the contractor can address main areas and concerns about microsurfacing quality.
  4. Focus agency construction quality assurance efforts on those microsurfacing factors that relate to the quality of the workmanship and other field-related aspects.
  5. Scratch coat and full lane-width microsurfacing can use the same size aggregate with no apparent difference in performance.
  6. The microsurfacing placement machine is best recalibrated every time there is a change in material source or composition.
- Case Study Effective Practices
  1. Microsurfacing can be effectively employed on roads where routine winter snow removal is a factor if the underlying pavement is structurally sound.
  2. Microsurfacing is a proper alternative to enhance skid resistance in areas where the frictional characteristics of the road's surface are to be restored to safe operating limits.
  3. The microsurfacing binder amount can be reduced by 1% to 2% in rut filling and scratch courses upon which a wearing course will be applied.

FUTURE RESEARCH NEEDS

The synthesis uncovered a number of gaps in the body of knowledge about microsurfacing. The following is a list of future research needs and a brief description of what form that research might take:

- Pavement preservation success depends on identifying candidate roadways before they need reactive maintenance. The survey found very little information regarding trigger points for invoking microsurfacing to extend the underlying pavement's life and preserve its structural integrity. Thus, research is needed to determine measurable values of distress that can be used in an agency's pavement preservation program. Additionally, microsurfacing success demands that the road be structurally sound. Therefore, research may also include consolidating agency pavement management system trigger values and furnishing guidance as to appropriate microsurfacing timing.

- There is no clear trend as to whether rolling adds value or not to the microsurfacing process; therefore, research to settle this question is suggested.
- Most of the agencies in the survey use the same design for microsurfacing on high-volume roads as they do on low-volume roads. Research is suggested that will either confirm or deny that this is good practice.
- The survey results that show that the majority of knowledgeable maintenance practitioners do not consider environmental impact in their project development process. Given the current widespread focus on sustainable design and construction practices, this research would be able to draw from the information currently being developed for other types of highway paving systems.
- One of the conclusions reported earlier documented the need for a microsurfacing certification program at the national level. Research to determine the specific content of such a program is suggested.
- Because several of the responding agencies are successfully using warranties, research to determine the appropriate characteristics of and effectiveness of microsurfacing warranties is suggested.
- Public highway agencies in Australia and New Zealand have long been using performance contracting techniques to procure pavement maintenance and preservation services. These contracts are based on objective key performance measures such as skid number, pavement macrotexture, and other criteria. The suggested research would evaluate the current programs used in those and other countries, such as the United Kingdom, South Africa, Portugal, and Spain, and develop a set of key performance measures that could be used in microsurfacing projects being procured on a performance basis.
- The lack of rigorous field tests based on a rational quantification of measurable microsurfacing properties leads to a suggestion for research to develop a series of field tests that allow an inspector to test the microsurfacing mix after it has been laid, as well as tests to identify when the mix has cured to a sufficient degree to open it to traffic without fear of damaging it.

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GLOSSARY AND ABBREVIATIONS

The terms found in this glossary came primarily from the International Slurry Surfacing Association's 2010 edition of its *Inspector's Manual for Slurry Systems*. Definitions for terms not contained in this reference were imported from various sources and are noted by "(author year)" as they occur.

GLOSSARY

Asphalt Emulsion—Defined by the most common type of system in which the asphalt is the dispersed liquid or the internal phase, and water is the dispersing liquid or the external phase. This is commonly called oil-in-water emulsion. During asphalt emulsion manufacture, the emulsifying agent promotes emulsification and keeps it stable thereafter. Different types of asphalt emulsions are shown in Table 51.

Adhesion Agents—These substances improve the degree of wetting of the aggregate by the binder, thus enhancing the adhesion between the binder and aggregate [*NCHRP Synthesis 340* (2005)].

Aggregate—A granular material, usually crushed and screened to appropriate gradations, that is used as the cover stone in a surface treatment [*NCHRP Synthesis 340* (2005)].

Binder—A bituminous material that provides a waterproof seal and also bonds the cover stone to the pavement [*NCHRP Synthesis 340* (2005)].

Bleeding—The upward movement of asphalt through the surface treatment. Bleeding, also commonly referred to as flushing, can be identified by dark patches of asphalt forming on the surface, most commonly in wheel paths or intersections [*NCHRP Synthesis 340* (2005)].

Breaking—The initial separation of the water from the emulsion, which can be detected by a marked color change from brown to black, and often by the release of fairly clear to straw-brown water. This characterizes the point when asphalt droplets begin to re-combine. The results in the deposition of the base asphalt on a paved surface and the material can no longer be hand worked.

Colloid—Any fine suspension of finely divided particles in a continuous medium.

Corrective Maintenance—Maintenance performed once a deficiency occurs in the pavement; that is, loss of friction, moderate to severe rutting, extensive cracking or raveling.

Crack Filling—The placement of materials into nonworking cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement. Working cracks are defined as those that experience significant horizontal movements, generally greater than about 2 mm (0.1 in.). Crack filling should be distinguished from crack sealing.

Crack Sealing—A maintenance procedure that involves placement of specialized materials into working cracks using unique configurations to reduce the intrusion of incompressibles into the crack and to prevent intrusion of water into the underlying pavement layers. Working cracks are defined as those that experience significant horizontal movements.

Cure—The entire process of breaking and set until the final mixture of emulsion and aggregate has lost all moisture resulting from evaporation or dehydration.

Curing—A slurry system has "cured" when the asphalt particles have re-combined into a continuous film surrounding the aggregates, and the majority of micro-droplets of water have been removed from the mat through evaporation or chemical reaction. At this point the surface is ready for traffic. It should be noted that final cure (total dehydration) can take periods of from two to four weeks.

Edge—The point that the aggregate in a slurry system treatment ends.

Emulsifier (see Surfactant).

Emulsified Binder—A liquid mixture of asphalt binder, water, and an emulsifying agent. Emulsions are either anionic (negatively charged) or cationic (positively charged). Emulsions are not as sensitive to moisture, inherently contain anti-stripping agents, and require much lower application temperatures than asphalt cements [*NCHRP Synthesis 340* (2005)].

Emulsion—Defined as a mixture of two immersible liquids, one of which is dispersed in the other in the form of very fine droplets, usually in the presence of a third component, the surface active agent.

Flushing—See definition for bleeding.

Ionic Compatibility—Different types of aggregate are better suited to certain binders as a result of electrostatic charges. For sufficient adhesion, the binder and aggregate must have opposite charges.

Lump Sum Contract—A contract where the contractor is required to furnish a single sum for the cost of completing the scope of work described in the plans and specifications. The contractor assumes the risk that actual quantities exceed contractor-estimated quantities and is not paid extra if they do [*NCHRP Synthesis 340* (2005)].

Macrotexture—Larger irregularities in the road surface (coarse-scale texture) that affects hysteresis. These larger irregularities are associated with voids between stone particles. The magnitude of this component will depend on several factors. The initial macrotexture on a pavement surface will be determined by the size, shape, and gradation of coarse aggregates used in pavement construction, as well as the particular construction techniques used in the placement of the pavement surface layer. Macrotexture is also essential in providing escape channels to water in the tire–surface interaction, thus reducing hydroplaning (Noyce et al. 2005).

Micro-Surface Emulsion—Polymer-modified emulsions with special chemical compositions enable placement of thick lifts of "slurry." They are normally cationic with a low pH.

Microtexture—Irregularities in the surfaces of the stone particles (fine-scale texture) that affect adhesion. These irregularities are what make the stone particles feel smooth or harsh to the touch. The magnitude of microtexture depends on initial roughness on the aggregate surface and the ability of the aggregate to retain this roughness against the polishing action of traffic (Noyce et al. 2005).

Modified Binder—Binder modifiers include polymers, latex, rubber crumb, and anti-stripping agents. Modifiers have proven successful at enhancing flexibility, minimizing bleeding, increasing aggregate retention, and extending the service life of microsurfacing [*NCHRP Synthesis 340* (2005)].

Particle Charge Test—The particle charge test is made to identify cationic emulsions. It is performed by immersing a positive electrode (anode) and a negative electrode (cathode) into a sample of emulsion and connecting them to a controlled direct-current electrical source. At the end of a specified time period, the electrodes are observed to determine which pole has an appreciable layer of asphalt deposited on it. Cationic emulsions will migrate towards the cathode.

Pavement Preservation—The sum of all activities undertaken to provide and maintain serviceable roadways. This includes corrective maintenance and preventive maintenance, as well as minor rehabilitation projects (Geiger 2005).

Pavement Preventive Maintenance—Planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without increasing the structural capacity) (Geiger 2005).

Pavement Reconstruction—Construction of the equivalent of a new pavement structure that usually involves complete removal and replacement of the existing pavement structure including new and/or recycled materials (Geiger 2005).

Pavement Rehabilitation—Work undertaken to extend the service life of an existing pavement. This includes the restoration, placing an overlay, and/or other work required to return an existing roadway to a condition of structural and functional adequacy (Geiger 2005).

Penetration—An empirical measure of consistency in which a container of asphalt cement is brought to a test temperature of 77°F in a water bath. A needle of prescribed dimension, loaded to a weight of 100 grams, is allowed to bear on the surface of the asphalt cement for 5 seconds. The unit of 0.1 mm, which the needle penetrates into the sample, is defined as the penetration.

Polymer-Modified Emulsion—These emulsions contain modifiers in the form of finely dispersed polymers. These modifiers are blended into the asphalt particles prior to the manufacturing of the emulsion or mixed with the asphalt particles during the milling process. Polymers are added to increase strength, reduce temperature susceptibility, and improve adhesion and stability.

Pug Mill—A chamber in which rotating shafts have paddles spaced along their length that are capable of being angled to advance or retard the movement of the mix through the mixing chamber. Spray bars for asphalt emulsion and/or water/set coat additives are usually mounted in the mixing chamber near the aggregate feed end. Proportioned materials, including aggregates and emulsified asphalts, are mixed together to yield a uniformly coated mixture.

Quick Set Emulsion—Emulsions for slurries set by a chemical reaction between the emulsifier and the aggregate and a small amount of additives in the slurry. CSS-1h emulsions can be formulated as quick-set emulsions. These are normally designated as a CQS-1h. Anionic quick-set emulsions are normally designated QS-1h.

Raveling—Also commonly referred to as shelling, it is the loss of aggregate from the surface treatment. Low binder application rates, inadequate rolling, cool weather construction, and incompatible binder and aggregate types are common factors that lead to raveling [*NCHRP Synthesis 340* (2005)].

Ralumac™—A cold thin surface paving solution consisting of a water-based polymer-modified asphalt emulsion, 100% crushed fine aggregate, mineral filler, water, and additives. On asphalt pavements it can be used for sealing, rut filling, and to improve a road's macrotexture. On concrete pavements it can be used for texturing, noise reduction, and repairing wheel path abrasion channels caused by studded tires (Road 2010).

Residue From Distillation—The distillation test provides a means of determining the relative proportion of asphalt cement and water in the emulsified asphalt. Some grades of emulsified asphalt also contain an oil distillate and the distillation test provides information on the amount of this material in the emulsion. Also, the distillation test provides an asphalt cement residue on which additional tests may be made

Ring & Bell Softening Point—The term relates a measure of consistency for asphalts. Samples of asphalt loaded with steel balls are confined in brass rings suspended in a beaker of water one inch above a metal plate. The liquid is heated at the prescribed rate. As the asphalt softens, the balls and asphalt gradually sink toward the plate. At the moment the asphalt touches the plate, the temperature of the water is recorded and this is designated as the Ring & Ball Softening Point.

Sand Patch—Also known as the sand circle test, a test for determining texture depth of a pavement surface (refer to ASTM E 965) [*NCHRP Synthesis 340* (2005)].

Set—The point during the breaking process when the asphalt aggregate mix will no longer track when blotted with white paper. (The mix may still be too tender for traffic at this point.)

Set Control Additives—Defined as small amounts of materials (mineral fillers or chemical) that when added to a slurry/microsurfacing mixture, speed or retard the setting characteristics of that mix.

Setting—A point when all asphalt particles have broken and combined into larger particles. This is observed when the material becomes rain safe and will support foot traffic.

Settlement—The settlement test detects the tendency of asphalt globules to settle during storage of emulsified

asphalt. A prescribed volume of material is allowed to stand in a graduated cylinder for a specified number of days. Small samples are then taken from the top and bottom parts in the cylinder. Each sample is placed in a beaker and weighed. The sample is then heated until water evaporates and the residue is then weighed. The weights obtained provide the basis for determining the difference, if any, between asphalt cement content in the upper and lower portions of the graduated cylinder, thus providing a measure of settlement.

Sieve Test—The sieve test complements the settlement test and has a somewhat similar purpose. It is used to determine quantitatively the percentage of asphalt present in the form of relatively large globules. Such globules do not provide thin and uniform coatings of asphalt on the aggregate particles and may or may not be detected by the settlement test. In the sieve test, a representative sample of emulsified asphalt is poured through a No. 20 sieve. For anionic emulsions the sieve and retained asphalt are then rinsed with a mild sodium oleate solution and finally with distilled water. For cationic emulsions, distilled water is used instead of sodium oleate solution. After rinsing, the sieve and asphalt are dried in an oven and the amount of retained asphalt determined.

Slow Set Emulsions—Asphalt emulsions that demonstrate very stable properties. These emulsions must be stable when diluted and also have a high resistance to chemical breakdown. The ability of the emulsion to mix with cement is an indication of its suitability for use with an aggregate with a high surface area. This type of emulsion for slurries is set almost entirely from the evaporation of the water. Typical designations are SS-1h (Anionic) and CSS-1h (Cationic).

Slurry Seal—A mixture of slow setting emulsified asphalt, well-graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of old pavements, to restore a uniform surface texture, to seal the surface to prevent moisture and air intrusion into the pavement, and to provide skid resistance.

Sprayed Seal—Australian terminology, essentially synonymous with a chip seal, which refers to the application a bituminous binder and cover aggregate on various surfaces [*NCHRP Synthesis 340* (2005)].

Stator—The fixed or stationary plate of a colloid mill. Emulsions are formed when two immiscible liquids are introduced into a cavity with a small clearance between the stator and a high-speed rotor creating high shear forces.

Streaking—An aesthetic and construction defect cause by nonuniform application of binder across the lane width. Streaking leads to a considerable shortening of the life expectancy of a surface treatment [*NCHRP Synthesis 340* (2005)].

Stripping—Separation of the binder from the aggregate. Refer to raveling.

Surface Texture—The characteristics of the pavement surface that contribute to both surface friction and noise.

Surface Treatment—A surface treatment, commonly referred to as a Bituminous Surface Treatment (BST) or Asphalt Surface Treatment (AST), is as an application of asphalt binder and cover aggregate on prepared gravel or crushed stone base [*NCHRP Synthesis 340* (2005)].

Surface Texture—The macroscopic and microscopic characteristics of the pavement surface. Surface texture depth is a metric that influences material application rates, design life, skid resistance, and road noise emissions [*NCHRP Synthesis 340* (2005)].

Surfactant (Surface Active Agent)—Any substance that alters the energy relationship at interfaces; e.g., organic compounds displaying surface activity such as detergents, wetting agents, dispersing agents, and emulsifiers.

Uniform Cross Section—The area where the pavement width is greater than the width of the slurry system treatment placed and there are no drop-offs greater than ½ inch (12 mm).

Unit Price Contract—A construction contact where the contractor furnishes unit prices (i.e., $ per pay unit) for each pay item in the contract and the contract is awarded to the lowest bidder computed by multiplying the contractor-furnished unit price with the engineer's estimated quantity for each pay item and extending that to a total bid price. The contractor is then paid its unit price for the actual quantities even if exceed the engineer's estimated quantities [*NCHRP Synthesis 340* (2005)].

Viscosity—The Saybolt Furol viscosity test as described for asphalt emulsions is used both for the anionic and cationic emulsified asphalts to measure and specify consistency properties. As a matter of testing convenience and also to achieve suitable testing accuracy, two testing temperatures [25°C (77°F) and 50°C (122°F)] are used, depending on the viscosity characteristics of the specific type and grade of the emulsified asphalts.

ABBREVIATIONS

The following are abbreviations used in the synthesis report:

BTU	British Thermal Units
C	Celsius
CO^2	Carbon dioxide
cm	Centimeter
CM	Cubic meter
CQS-P	See Table 51 in chapter eight
CQS-1H	See Table 51 in chapter eight
CQS-1HP	See Table 51 in chapter eight
CSS-1	See Table 51 in chapter eight
CSS-1P	See Table 51 in chapter eight
CSS-1H	See Table 51 in chapter eight
CSS-1HP	See Table 51 in chapter eight
CY	Cubic yard
DOT	Department of Transportation (U.S. state)
F	Fahrenheit
FLHD	Federal Lands Highway Division
Ft	Foot
G	Gram
gal	Gallon
in.	Inch
kg	Kilogram

km	Kilometer
l	Liter
lb	Pound
MG	Megagram
MJ	Megajoule
mm	Millimeter
MOT	Ministry of Transportation (Canadian province/ territory)
NO^2	Nitrogen dioxide
QC/QA	Quality control/quality assurance
SBS	Styrene butadiene styrene
SM	Square meter
SN	Skid number
SS-1	See Table 51 in chapter eight
SS-1H	See Table 51 in chapter eight
NCAT	National Center for Asphalt Technology
NHI	National Highway Institute
U.S.	United States

APPENDIX A

Survey Questionnaire and Results

NCHRP Synthesis Topic 41-12
Microsurfacing Best Practices

Questionnaire for Public Agencies and Others

PURPOSE OF THE SYNTHESIS:

The purpose of this synthesis is to capture the various ways federal, state and local transportation agencies are utilizing microsurfacing as a preventive maintenance and/or pavement preservation treatment. The synthesis will identify different approaches and effective practices recognizing the differences in each of the climatic regions. The synthesis will also address how the agencies in the study utilize microsurfacing in high and low volume traffic conditions. You have been identified as a knowledgeable source for this information and we would like to synthesize your experience with other pavement maintenance professionals in the US and overseas to determine those practices that have produced successful microsurfacing projects.

This questionnaire will take approximately 45 minutes to complete. The purpose of this questionnaire is to collect specific information on microsurfacing practices from sources ranging from the municipal to the international level. Additionally, those respondents that believe that they have a microsurfacing project that would make a good case study to illustrate a particularly successful microsurfacing best practice are invited to indicate their willingness to contribute detailed information about the project, and they will be contacted individually by the researcher to obtain the case study information.

The results of this synthesis will be shared and distributed through AASHTO, the Federal Highway Administration, Transportation Research Board, and others, with the goal of assisting in the development and implementation of microsurfacing as a part of pavement preservation programs. I want to thank you in advance for your support for this project. This project's results will furnish a means to disseminate the experience of maintenance engineers from around the world in a very straightforward fashion. Thank you for your time and information.

Douglas D. Gransberg, PhD, PE

Question 1 [Mandatory]

Respondent Information Point of Contact Name; contact info:

Question 2

Type of Agency/Organization:

☐ Federal Agency; ☐ State/Provincial Agency; ☐ County Agency; ☐ Municipal Agency; ☐ Private

Question 3

If you checked private organization, what type?

Question 4

If private, what is your involvement in microsurfacing?

Question 5

Does your agency use microsurfacing in its pavement maintenance and/or pavement preservation program?

☐ Yes ☐ No [Skip to End]

Additional Comment (if you'd like to further explain):

General Program Information: (Non-agency respondents, please skip to question 11)

Question 6

At this time, what proportion of your agency's highway centerline miles have microsurfacing as the surface wearing course? Example: 200 miles maintained & 180 miles with micro = 200/180

Question 7

Do you follow a specific preventive maintenance cycle for microsurfacing?

☐ Yes ☐ No ☐ Don't know

Question 8

If yes, what is the cycle length? (i.e., roughly how many years)

Question 9

How much microsurfacing work does your agency do each year?

Approximately $/year of national currency/year
Which includes approximately center-line miles/km per year

Question 10

What percentage of your microsurfacing work is done with in-house crews?

% is done in-house

Question 11

How do you rate your organization's overall experience with the performance of microsurfacing?

	Unacceptable	**Poor**	**Good**	**Excellent**	**Not Applicable**
Contract Crew	☐	☐	☐	☐	☐
In-house Crew	☐	☐	☐	☐	☐

Question 12

What is the typical service life of microsurfacing projects with which you have been involved (i.e., how many years do they typically last)? NOTE: You will be asked for the design life (the life you use in the design process) in the next section.

Typical service life = years

Design Procedures: Non-agency respondents—please answer the questions for a typical agency with which you have worked.

Question 13

Does your organization use a formal design process for microsurfacing projects?

☐ Yes ☐ No ☐ Don't know

Question 14 [Mandatory]

What is the major reason for organization’s decision to apply a microsurfacing to a given pavement? (Check only one.)	
☐ Distress (cracking)	☐ Oxidation
☐ Improve friction (skid) resistance	☐ Raveling
☐ Prevent water infiltration	☐ Fill surface rutting
☐ Provide a surface wearing course	☐ Improve striping visibility
Other, please specify:	

Question 15 [Mandatory]

Who performs the design?	
☐ Agency in-house design section performs the design	☐ Design consultant performs the design under design contract
☐ Agency in-house materials lab section performs the design	☐ Microsurfacing contractor performs the design under the construction contract
☐ Agency in-house construction group performs the design	☐ Don't know
☐ Agency in-house maintenance group performs the design	Other; Please specify:

Question 16

If design is by others, does your agency review and approve/accept the design?

☐ Yes ☐ No ☐ Don't know Other, please specify:

Question 17

What is the "trigger point" (i.e., the condition that makes you decide to place a new treatment) in your microsurfacing decision-making process? (Check all that apply.)	
☐ Pavement condition rating or index	☐ Age of the surface
☐ Level/amount of cracking	☐ Roughness (IRI or other metric)
☐ Friction/skid number	☐ Rutting
☐ Amount of oxidation	☐ No trigger point
Other, please specify:	

Question 18

Does your agency consider environmental aspects of microsurfacing (e.g., emulsion versus hot-mix energy usage, preservation versus rehabilitation, etc.) as part of the treatment selection process?

☐ Yes ☐ No ☐ Don't know

If yes, please explain how it is considered:

Question 19

Microsurfacing is often used to restore friction/skid resistance. Before microsurfacing is placed, how does a road's existing friction/skid number compare to your agency's minimum friction/skid resistance standards?

☐ Lower than minimum ☐ At or close to minimums ☐ Above minimums
☐ No friction/skid number standards used in this context
☐ Varies. Could be below, at, above the minimum standards.

Question 20

How would you describe the level of distress (cracking, etc.) on roads that generally receive a microsurfacing?

☐ Severe ☐ Moderate ☐ Slight ☐ None

Question 21

How do you characterize the roadway's structural integrity (e.g., pavement, base, and subbase) that generally receives a microsurfacing?

☐ Excellent ☐ Good ☐ Fair ☐ Poor ☐ Very Poor

Question 22

How do you characterize existing pavement conditions before the design of microsurfacing applications?

☐ Roughness (IRI or other metric); ☐ Level of oxidation; ☐ Qualitative (visual) factors
☐ We do not characterize existing conditions

Question 23

What is the design procedure(s) you use/or permit?

☐ ISSA A 143 Method ☐ ASTM D 3910-98 Method ☐ ASTM D 6372-99a Method
☐ Texas Transportation Institute Method (TTI-1289) ☐ Austroads AGPT04K/09 Method
☐ Benedict "Proposed Performance" Design Method ☐ Empirical method based on past experience
☐ No formal design method Individual organizational method, please specify:

If you answered "Individual organizational method" to the above question, if possible, please briefly describe your process in a Word document and e-mail copy of your design method to: dgransberg@ou.edu after you complete the survey.

Question 24

How many years has your agency used the design procedure(s) you identified in the previous question?

☐ Less than 1 year ☐ 1 to 5 years ☐ 5 to 10 years ☐ More than 10 years ☐ Don't know

Question 25

What is the typical design life in years for microsurfacing projects in your agency?

Question 26

What design criteria is used? (Check all that apply.)

☐ Pavement condition	☐ Absorption factor/oxidation	☐ Traffic volume
☐ Turning movements	☐ Percent trucks	☐ Texture factor
☐ Weather (cold/hot/rain/humidity)	☐ Precoat condition (green/dry)	☐ Source of materials
☐ Residual binder factor	☐ Number and width of lanes	☐ Grade/steepness factor
☐ Daily construction working window (hours of work)	Other, please specify:	

Question 27

Do you vary the material design with regard to types of highways (e.g., urban, rural, etc.)?

☐ Yes ☐ No ☐ Don't know

Question 28

If the answer to the previous question is yes, what are the factors used to differentiate between the different requirements?

☐ Number of lanes ☐ Average Daily Traffic ☐ Number of ESALs
☐ Proximity to urban areas ☐ Proximity to rural areas Other, please specify:

Question 29

When field conditions warrant, do you apply a scratch (leveling) course in your typical microsurfacing design?

☐ Yes ☐ No ☐ Don't know

Question 30

If the answer to the above question is yes, how does the size of aggregate in the scratch course differ from the surface course?

☐ Scratch coat aggregate is smaller ☐ Scratch coat aggregate is larger
☐ No change in scratch coat aggregate size ☐ Don’t know Other, please specify:

Contracting Procedures:
Non-agency respondents—please answer the questions for a typical agency with which you have worked.

Question 31

Do you feel that an adequate number of experienced microsurfacing contractors bid for your jobs?

☐ Yes ☐ No ☐ Don't know

Question 32

How many microsurfacing contractors typically bid your jobs?

☐ 1–3 ☐ 4–6 ☐ 7–9 ☐ 10 or more

Question 33

Which statement below best fits the annual volume of your agency's microsurfacing program?

☐ We let virtually the same amount of microsurfacing every year.
☐ Our microsurfacing program fluctuates + 20% each year.
☐ Our microsurfacing program fluctuates + 50% each year.
☐ We rarely know how much microsurfacing we are going to do each year.
Other, please specify:

Question 34

Do you have a prequalified list of contractors who are allowed to bid on your microsurfacing projects?

☐ Yes ☐ No ☐ Don't know

Question 35

Do you require training and/or certification for contractor personnel?

☐ Yes ☐ No ☐ Don't know

Question 36

If yes, what type of training or certification?

Question 37

Do you require training and/or certification for agency personnel?

☐ Yes ☐ No ☐ Don't know

Question 38

If yes, what type of training or certification?

Question 39

Do you require warranties in your microsurfacing projects?

☐ Yes ☐ No ☐ Don't know

Question 40

If yes, what is the length of the warranty and what criteria (threshold values) are required?

Question 41

In which months do you typically apply microsurfacing?

☐ January	☐ May	☐ September
☐ February	☐ June	☐ October
☐ March	☐ July	☐ November
☐ April	☐ August	☐ December

Question 42

What types of contracts do you use for microsurfacing projects? (Check all that apply.)

☐ Unit price-low bid ☐ Lump sum/firm fixed price ☐ Cost plus
☐ Indefinite delivery/indefinite quantity ☐ Design-build Other, please specify:

Question 43

What units do you use to measure and pay for microsurfacing binder?

☐ Square yard/square meter ☐ Gallon/liter ☐ Ton/tonne/megagram Other, please specify:

Question 44

Please indicate your agency's reasons for using the pay units you selected above for binder.

	Shifts the quantity risk to the contractor	**Reduces the cost**	**Fairest to the contractor**	**Easier to accurately estimate**	**Don't know why we use them**
Units of Area (SY/SM)	☐	☐	☐	☐	☐
Units of Volume (Gal/liter)	☐	☐	☐	☐	☐
Units of Weight (ton/tonne/MG)	☐	☐	☐	☐	☐

Question 45

What units do you use to measure and pay for microsurfacing aggregate?

Question 46

Please indicate your agency's reasons for using the pay units you selected above for aggregate.

	Shifts the quantity risk to the contractor	Reduces the cost	Fairest to the contractor	Easier to accurately estimate	Don't know why we use them
Units of Area (SY/SM)	☐	☐	☐	☐	☐
Units of Volume (CY/CM)	☐	☐	☐	☐	☐
Units of Weight (ton/tonne/MG)	☐	☐	☐	☐	☐

Question 47

How long is a typical microsurfacing project?

Centerline miles OR Centerline kilometers

Question 48

What is the maximum traffic volume on roads to which your agency applies microsurfacing?

☐ ADT < 1000 ☐ ADT < 2000 ☐ ADT < 5000 ☐ ADT < 20,000 ☐ ADT > 20,000

Materials:
Non-agency respondents—please answer the questions for a typical agency with which you have worked.

TABLE 2-2 ASTM Types I, II, and III Gradations

Sieve Size		Percent Passing by Weight			Stockpile Tolerance, %
in	mm	Type I	Type II	Type III	
3/8	9.500	100	100	100	
No. 4	4.750	100	90-100	70-90	+/- 5
No. 8	2.360	90-100	65-90	45-70	+/- 5
No. 16	1.180	65-90	45-70	28-50	+/- 5
No. 30	0.600	40-60	30-50	19-34	+/- 5
No. 50	0.300	25-42	18-30	12-25	+/- 4
No. 100	0.150	15-30	10-21	7-18	+/- 3
No. 200	0.075	10-20	5-15	5-15	+/- 2

Question 49

What aggregate gradation(s) shown in Table 2-2 do you use for your microsurfacing surface wearing course? (Check all that apply.)

☐ Type I ☐ Type II ☐ Type III Other: Please Specify:

Question 50

Which gradation is most commonly used?

☐ Type I ☐ Type II ☐ Type III Other: Please Specify:

Question 51

Are any special gradations used?

☐ Yes ☐ No ☐ Don't know If Yes, please specify the special gradations:

Question 52

What is the annual breakdown, on an approximate percentage basis, for the binders that your agency typically uses for microsurfacing projects?

Binder	% of Program	Binder	% of Program
SS-1		CQS-P	
SS-1H		CQS-1H	
CSS-1		CQS-1HP	
CSS-1P		LMCQS-1H	
CSS-1H		Ralumac	
CSS-1HP		Quick Set Mixing Grade	
Other: Please Specify binder and %:			

Question 53

How do you select the binder type for microsurfacing jobs?

☐ Local climate ☐ Traffic volume or ESALs ☐ Weather conditions in which seal will be applied
☐ Identified during design ☐ Compatibility with aggregate ☐ Past experience
Other, please specify:

Question 54

Do you use modifiers with your base asphalt or binder?

☐ Yes ☐ No ☐ Don't know

Question 55

If yes, what modifiers are used?

☐ Polymers ☐ Latex ☐ Additives ☐ Anti-stripping agents ☐ Styrene Butadiene Rubber (SBR)
☐ SBR—Polyisoprene ☐ SBR—Thermoplastic Elastomers Other, please specify:

Equipment:
Non-agency respondents—please answer the questions for a typical agency with which you have worked.

Question 56

What type of mixing equipment do you require?

☐ Continuous self-propelled ☐ Truck-mounted ☐ Both Other, please specify:

Question 57

Do you require computer controlled mixing equipment?

☐ Yes ☐ No ☐ Don't know

Question 58

What type of mixture controls do you require?

☐ Computer ☐ Revolution counter Other: Please specify:

Question 59

What roller types are considered appropriate for use on microsurfacing?

☐ Static steel ☐ Pneumatic-tired ☐ Combination pneumatic/steel
☐ Vibratory rollers ☐ No rollers used

Question 60—Choice—One Answer (Drop Down)

Do you require any specific makes and models (proprietary specifications) for the microsurfacing equipment?

☐ Yes ☐ No ☐ Don't know

Question 61

If the answer to the above question is yes, which types have specified makes or models?

☐ Mixing equipment ☐ Rolling equipment ☐ Spreader boxes ☐ Traffic control equipment/devices

Quality Assurance and Quality Control:
Non-agency respondents—please answer the questions for a typical agency with which you have worked.

Question 62

Who conducts the inspection of construction operations?

☐ Your agency ☐ Private consultant ☐ Contractor Other, please specify

Question 63

Do you use an independent laboratory to evaluate microsurfacing mix design?

☐ Yes ☐ No ☐ Don't know

Question 64

Does your agency have an incentive/disincentive pay factor for the aggregate meeting the target submitted on the mix design?

☐ Yes ☐ No ☐ Don't know

Question 65

If the answer is yes to the above, please indicate the nature of the incentive/disincentive program?

The incentive/disincentive program is:

Question 66

Which of the following mix design tests are performed on your projects?

☐ Residual Asphalt Content ☐ Penetration ☐ Softening Point ☐ Sand equivalent ☐ Soundness
☐ Abrasion resistance ☐ Wet Stripping Test ISSA 114 ☐ Tests for the presence of clay
☐ Percent Sodium Sulfate Loss (resistance to freeze/thaw) ☐ Consistency Test ISSA TB 106
☐ Modified Cohesion Test ISSA TB 139 ☐ Loaded Wheel Test ISSA TB 109 ☐ Wet-Track Abrasion
☐ ISSA TB 100 ☐ Set Time Test ☐ Cure Time Test ISSA TB 139
☐ Lateral Displacement Test ISSA TB 147 ☐ Classification Test ISSA TB 144
☐ Mix Time Test ISSA TB 113 ☐ Modified Cup Flow Test ☐ TTI Mixing Test
☐ Compatibility of aggregate with binder

Question 67

Do you perform any field tests to monitor the quality of the mix?

☐ Yes ☐ No ☐ Don't know

Question 68

If yes, what tests are done?

Question 69

Do you take field material samples for compliance testing?

☐ Yes ☐ No ☐ Don't know

Question 70

If yes, who takes the samples?

☐ Agency personnel ☐ General Engineering Consultant ☐ Contractor ☐ Independent lab

Question 71

When testing and accepting the aggregate for specification compliance, where is the acceptance test conducted?

☐ The pit/source ☐ The stockpile ☐ While transferring into the nurse units
☐ Just before it enters the microsurfacing paver mixing chamber ☐ Don't know

Question 72

Do you require calibration of mixing equipment?

☐ Yes, in the field ☐ Yes, not in the field. Contractor furnishes a submittal that verifies the calibration.
☐ No ☐ Don't know

Question 73

If yes, how often?

Question 74

Do you require calibration of spreading equipment?

☐ Yes, in the field ☐ Yes, Contractor furnishes a submittal verifies the calibration
☐ No ☐ Don't know

Question 75

If Yes, how often?

Question 76

What tolerances are allowed for testing mix designs?

TEST	TOLERANCES
Mix design testing	
Stockpile testing	
Emulsion testing	
Other testing	

Question 77

Beyond calibration of mixing and spreading equipment, do you perform any other field tests to check material application rates?

☐ Yes ☐ No ☐ Don't know

Question 78

If yes, what tests are done? Please e-mail a copy of the test to dgransberg@ou.edu if possible.

Product Performance:
Non-agency respondents—please answer the questions for a typical agency with which you have worked.

Question 79

How does your organization define "success" for a microsurfacing project?

☐ Meets expected service life ☐ Does not fail shortly after construction
☐ Achieves desired friction/skid number ☐ Qualitative measures—look, color, etc.
☐ Meets project specification

Question 80

What common distresses are observed in your completed microsurfacing projects?

☐ Raveling ☐ Bleeding ☐ Corrugation ☐ Crack reflection ☐ Streaking ☐ Transverse joints
☐ Longitudinal Joints Other; Please specify:

Question 81

Rate these factors as to their impact in minimizing microsurfacing defects?

	Most Impact	Some impact	Neutral	Little impact	No Impact
Design Method					
Better Binder					
Better Aggregates					
Construction Procedure					
Contractor Experience					
QA/QC Program					
Preconstruction road preparation					
Selecting the right project					

Question 82

What is the most common public-user complaint about microsurfacing? (Check one only.)

☐ Loose stone ☐ Road noise ☐ Vehicle ride ☐ Appearance ☐ Don't know
☐ We don't get complaints

Question 83

How would you generally describe the pavement ride on roads after they receive a new microsurface?

☐ Excellent ☐ Good ☐ Fair ☐ Poor ☐ Very Poor

Question 84

If your organization had microsurfacing failures, which of the following were a likely cause?

☐ Weather ☐ Improper application rate ☐ Dirty or dusty aggregate ☐ Aggregate gradation
☐ Improper ambient and/or pavement temperature ☐ Improper binder viscosity
☐ Improper binder temperature ☐ Not applicable Other, Please specify:

Question 85

Which factors are most critical in achieving the required service life of your microsurfacing projects?

☐ Original substrate surface quality ☐ Underlying pavement structure ☐ Maintenance funding
☐ Friction loss ☐ Traffic ☐ Cold climate considerations (freeze/thaw cycles, snowplowing, etc.)

Question 86

Which methods do you use to maintain your microsurfaced roads? (Check all that apply.)

☐ Crack sealing ☐ Surface treatments (seal coat) ☐ Fog seal ☐ None ☐ I don't know

Question 87

If there is anything that you would like to add that was not covered in this questionnaire that you feel would benefit this study, please write your comments below:

Additional comments:

Thank you very much for your contribution. If you input your e-mail on the initial page, you will be sent a link where you can download a free copy of the completed synthesis when it is completed. In the meantime, feel free to give me a call if you have questions on this subject.

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TABLE A1
SUMMARY OF SURVEY RESPONSES

Agency	Use Micro?	Agency	Use Micro?	Agency	Use Micro?	Agency	Use Micro?
AK	No	KS	Yes	OK	Yes	AB	Yes
AL	Yes	LA	Yes	OR	No	BC	Yes
AR	No	MI	Yes	OR-W	No	MNT	Yes
AZ	Yes	MN	Yes	PA	Yes	NB	Yes
CA	Yes	MO	Yes	RI	No	NF	No
CN	No	MS	Yes	SC	Yes	NS	Yes
CO	No	MT	No	SD	Yes	NWT	No
DE	Yes	NC	Yes	TN	Yes	ON	Yes
FL	No	ND	Yes	TX	Yes	PEI	No
GA	No	NH	Yes	UT	Yes	QB	Yes
HI	No	NJ*	Yes	VA	Yes	SA	Yes
IA	Yes	NM	Yes	VT	No	YK	No
ID	No	NV	Yes	WA	No	AU—Vic	Yes
IL	Yes	NY	yes	WI*	Yes	NZ—Cant	Yes
IN	Yes	OH*	Yes	WY	Yes	NZ—Well	Yes

* Responded “yes” to survey, but did not submit a complete response.

Table A2
COMPLETE SURVEY RESPONSES TO INDIVIDUAL QUESTIONS

State/Prov	Question 2: State/Provincial Agency	Question 5: Does your agency use microsurfacing in its pavement maintenance and/or pavement preservation program?	Question 6: Rural – Local (Total miles/KM maintained-Miles/KM with Microsurfacing)	Question 6: Rural – Interstate (Total miles/KM maintained-Miles/KM with Microsurfacing)	Question 6: Urban – Local (Total miles/KM maintained-Miles/KM with Microsurfacing)	Question 6: Urban – Interstate (Total miles/KM maintained-Miles/KM with Microsurfacing)	Question 7: Do you follow a specific preventive maintenance cycle for microsurfacing?	Question 8: If yes, what is the cycle length? (i.e. roughly how many years)	Question 9: Approximately $/year of National currency/year $millions	Question 9: Which includes approximately center-line miles/KM per year	Question 10: What percentage of your microsurfacing work is done with in-house crew	Question 11: Contract crew	Question 11: In-house crew	Question 12: What is the typical service life of a microsurfacing projects with which you have been involved? (i.e how many years do they typically last) NOTE: You will be asked for the design life	Question 13: Does your organization use a formal design process for microsurfacing projects	Question 14: What is the major reason for organization's decision to apply a microsurfacing to a given pavement? (Check only one)
AL	X	Yes					No			60 miles	0	4	6	5	Yes	Other
AZ	X	Yes		2000/110m	5000/90		No		$2M	40 center-	0	5	6	5 years	No	Raveling
CA	X	Yes			10569/335		No		2.5M	20	0	4	6	4-6 years	Yes	Surface course
DE	X	Yes					No		500000		0	4	6	unsure	No	Seal water
IA	X	Yes	250/9600	0	0	0	DK		$500,000	10 miles	0	4	6	8 years	Yes	Oxidation
IL	X	Yes	Unk	Unk	Unk	Unk	No		Variable		0	3	6	DK	No	Other
IN	X	Yes					Yes	8to12	$5-6 million	149	0	4	6	8	Yes	Oxidation
KS	X	Yes	8880/140	485/15	115/0	50/0	No		1 mil	30	0	4	6	5	No	Rutting
LA	X	Yes	18,394/63				DK		$6.28M	63	0%	4	6	6-8 years	No	Rutting
MI	X	Yes	253	30	115	16	No		2 mil	60	0	4	6	5	Yes	Seal water
MN	X	Yes				100	No		3 mil	100 miles	5%	5	4	5 to 7 years	Yes	PM
MO	X	Yes	0/	0/23,000	0/	12.5/11K	No		$591,500	12.5	None.	4	6	7 years	Yes	Surface course
NC	X	Yes	79,000/63	79,000/62	79,000/14		No		$1.9 million/yr	48	none	4	6	DK	DK	Seal water
ND	X	Yes	7072/211	1023/137	297/8	119/0	No		2008: $6,355,00	119	0	4	6	7 years	Yes	Surface course
NH	X	Yes	4550/10	4560/25			No		1-2 mil	5to15	0	4	6	20	Yes	Seal water
NM	X	Yes	9,871/188	891/50	1,135/214	109/69	No		5 mil	143	0	4	6	4	No	Seal water

1	2	5	6	6	6	6	7	8	9	9	10	11	11	12	13	14
NV	X	Yes	4330/98	460/1	488/70	105/2	No		$3.6M	43 miles/y	0	4	6	2-4 years	No	Surface course
NY	x	yes	9081/850	836/25	4200/100	852/25	No		5 mil	150	0	4	6	6 to 8	Yes	Oxidation
OK	X	Yes	0	0	3%	0	No		$2M	12 miles	$2M	2	6	7	No	Surface course
PA	X	Yes	28,021/280	847/12	10K/113	505/5	No		2.2mil	102		4	6	7-May	Yes	Raveling
SC	X	Yes	28170/67	580/0	11520/40	262/0	No		2.7 mil	53	0	4	6	6	No	Surface course
SD	X	Yes	?				No		10000		0	3	6	5	No	Skid
TN	X	Yes	12996/530	1100/8			No		9367120	139	0	4	6	6 to 8	Yes	Seal water
TX	x	Yes	640K/15K				No		$12 million/year		0	3	6	4 to 7 years	No	Surface course
UT	X	Yes	4300/43	770/102	600/98	170/10	Yes		6 mil	40-50	0	4	6	8-May	Yes	Surface course
VA	X	Yes	10% of system				No				0	4	6	7-May	No	Cracking
WY	X	Yes	4958/12	1980/286	304/8	189/0	No		$2.5M	30	0	4	6	1-=15	Yes	Surface course
AB	X	Yes	32K/100K				No		$60,000 Cdn/ye	25 to 40 km	0%	4	6	3 to 8	No	Raveling
BC	X	Yes		limited			No					4	6	5	Yes	Seal water
MNT	X	Yes		553/12665			No		$9m	170km	0	4	6	10yr	No	Rutting
NB	X	Yes					No		1.25 mi;	16km	0	4	6	5	No	Rutting
NS	X	Yes		2000/360			Yes	5to7	2-3mil	40-60km	0	5	6	7	No	Raveling
ON	X	Yes		606		49	No		3.6mol	65	0	4	6	7to9	No	Rutting
QB	X	Yes		2000/100			No				some	4	2	7	Yes	Oxidation
SA	X	Yes					No		10mil	200km	5	5	4	5to7	Yes	Rutting
AU	X	Yes	0	5	0	0	No		up to $2 millio	50	nil	4	6	No data as we	No	Oxidation
NZ - Cant		Yes					No					4	4	7-8 years on av	Yes	Surface course
NZ - Well		Yes					No					4	4	7-8 years on av	Yes	Surface course

State/Prov	Question 15: Who performs the design?	Question 16: If design is by others, does your agency review and approve/accept the design?	Question 17: "trigger point" Pavement condition rating or index	Question 17: Level/amount of cracking	Question 17: Friction/skid number	Question 17: Amount of oxidation	Question 17: Age of the	Question 17: Roughness (IRI or other metric)	Question 17: Rutting	Question 17: No trigger point	Question 18: Does your agency consider environmental aspects of microsurfacing (e.g. emulsion versus hot-mix energy usage)	Question 19: Microsurfacing is often used to restore friction/skid resistance. Before microsurfacing is placed, how does a road's existing friction/skid number compare to your	Question 20: How would you describe the level of distress (cracking, etc.) on roads that generally receive a microsurfacing?	Question 21: How do you characterize the roadway's structural integrity (e.g.; pavement, base and subbase) that generally receives a microsurfacing?	Question 22 characterize existing pavement:	Question 22: Level of Oxidation	Question 22: Qualitative(visual) factors	Question 22: We do not characterize existing conditions	Question 23: ISSA A 143 Method	Question 23: ASTM D 3910-98 Method	Question 23: ASTM D 6372-99a Method	Question 23: TTI Method	Question 23: Austroads AGPT04K/09 Method	Question 23: Benedict "Proposed Performance"	Question 23: Empirical method based on past	Question 23: No formal design method	Question 23: Individual organizational method,	Question 24: How many years has your agency used the design procedure(s) you identified in the previous question?
AL	Agency (mat'ls)	Yes	X								No	Varies.	Slight	Good			X										Spe	1to5
AZ	Contractor	Yes		X	X	X			X		Yes	Varies.	Slight	Good	X	X	X								X			DK
CA	Contractor	Yes		X			X				No	None	Slight	Good			X											5to10
DE	Agency (maint)		X								No	None	Slight	Good			X								X			1to5
IA	Contractor	Yes							X		No	Varies.	None	Good				X										>10
IL	Other	Yes								X	No	None	Moderate	Good			X											1to5
IN	Contractor	Yes			X		X		X		No	Varies.	Slight	Good		X											con	DK
KS	Contractor	Yes	X	X				X	X		No	Varies.	Slight	Good	X													>10
LA	Contractor	Yes						X			No	None	Slight	Fair												X		1to5
MI	Contractor	Yes		X			X	X	X		No	None	Slight	Excellent	X													5to10
MN	Contractor	Yes			X	X	X		X		No	None	Moderate	Fair		X			X									>10
MO	Agency (des)	NA	X	X	X			X			No	Lower	Moderate	Good	X		X											>10
NC	DK		X	X	X	X	X		X		No	None	Moderate	Good	X	X				X	X							1to5
ND	Contractor	Yes	X			X			X		No	None	Moderate	Fair				X		X								1to5
NH	Contractor	Yes					X				No	None	None	Excellent			X										con	1to5
NM	Contractor	Yes	X			X			X		No	None	Moderate	Good			X										NM	1to5

1	15	16	17	17	17	17	17	17	17	17	18	19	20	21	22	22	22	22	23	23	23	23	23	23	23	23	23	24
NV	Contractor	Yes		X	X	X	X		X		No	Varies.	Slight	Good			X			X					X			1to5
NY	Contractor	Yes	X	X		X					No	Above	Moderate	Good			X		X								colc	>10
OK	Agency (maint)	NA	X		X		X				No	Varies.	Moderate	Good	X		X								X			1to5
PA	Agency (des)	NA		X	X	X	X		X		Yes	Varies.	Moderate	Good	X	X	X									X		1to5
SC	Contractor	DK	X	X		X		X	X		No	None	Slight	Good			X										Ace	1to5
SD	Contractor	NA			X						No	Lower	Moderate	Good				X								X		DK
TN	Contractor	Yes	X	X	X	X	X				No	DK	Slight	Excellent				X										>10
TX	Contractor	Yes	X		X						No	Minimum	Moderate	Fair					X			X						>10
UT	Contractor	Yes	X	X	X	X	X	X	X	X	No	Varies.	Slight	Good	X		X				X							5to10
VA	Contractor	Yes	X				X	X			Yes	Above	Slight	Good			X										VD(	>10
WY	Contractor	Yes	X				X		X		No	Varies.	Moderate	Good	X		X											5to10
AB	Contractor	Other	X								No	None	Moderate	Excellent			X									X		DK
BC	Contractor	Yes	X	X			X		X		Yes	None	Moderate	Good			X											1to5
MNT	Agency (mat'ls)	NA							X		No	None	Slight	Good	X		X								X			5to10
NB	Agency (des)	NA								X	No	None	None	Excellent			X									X		DK
NS	Contractor	No			X		X		X		No	None	Moderate	Excellent			X											5to10
ON	Contractor	Yes	X	X	X	X		X	X		No	Varies.	Moderate	Good	X											X		>10
QB	Contractor	Yes			X		X				No	Varies.	Slight	Good	X													1to5
SA	Contractor	Yes	X					X	X		Yes	None	Moderate	Fair			X											5to10
AU	Contractor	Yes	X			X					Yes	None	Moderate	Good			X									X		<1
NZ - C	Contractor	NA			X	X	X		X		No	Varies.	Slight	Good			X											>10
NZ - V	Contractor	NA			X	X	X		X		No	Varies.	Slight	Good			X											>10

State/Prov	Question 25: What is the typical design life in years for microsurfacing projects in your agency?	Question 26 design procedure: Pavement	Question 26: Absorption Factor/Oxidation	Question 26: Traffic Volume	Question 26: Turning Movements	Question 26: Percent trucks	Question 26: Texture factor	Question 26: Weather	Question 26: Precoat condition (green/dry)	Question 26: Source of materials	Question 26: Residual binder factor	Question 26: Number and width of lanes	Question 26: Grade/steepness factor	Question 26: Daily construction working window (hours of work)	Question 27: Do you vary the material design with regard to types of highways ?	Question 28: Average Daily Traffic	Question 28: Number of ESALs	Question 28: Proximity to urban areas	Question 28: Proximity to rural areas	Question 29: When field conditions warrant, do you apply a scratch (leveling) course in your typical microsurfacing design	Question 30: If the answer to the above question is yes, how does the size of aggregate in the scratch course differ from the surface course?	Question 31: Do you feel that an adequate number of experienced microsurfacing contractors bid for your jobs	Question 32: How many microsurfacing contractors typically bid your jobs?	Question 33: Which statement below best fits the annual volume of your agency's microsurfacing program?	Question 34: Do you have a prequalified list of contractors who are allowed to bid on your microsurfacing projects?	Question 35: Do you require training and/or certification for contractor personnel?
AL	6 to 7	X		X		X				X		X			No					Yes	DK	DK	1to3	Other	DK	DK
AZ	5 years	X		X	X							X		X	DK					Yes	Same	No	1to3	Different	DK	DK
CA	5 years	X		X		X		X			X			X	Yes	X				Yes	Same	Yes	4to6	Different	No;	No;
DE	5	X		X		X									No					No		No	1to3	Same	No;	No;
IA	5 years	X	X	X						X					DK					No	Same	Yes	1to3	Different	Yes;	DK;
IL	DK														DK					Yes	Other	No	1to3	Other	Yes;	No;
IN	8														DK					Yes	Same	No	1to3	Other	Yes;	No;
KS	5	X													No					Yes	Same	Yes	1to3	Different	Yes;	No;
LA	6 to 8	X						X							No					Yes	Same	No	1to3	Other	No;	DK
MI	none	X		X			X	X		X	X	X	X		Yes	X				Yes	Scratch co	No	1to3	20%	No;	No;
MN	5 to 7									X					No					Yes	Same	Yes	1to3	Same	No;	No;
MO	7 to10	X	X	X		X					X				Yes		X	X	X	Yes	Smaller	Yes	4to6	Same	Yes;	DK
NC	7	X	X	X		X						X			DK					Yes	Same	No	1to3	Different	No;	DK
ND	7 to10	X								X					No					Yes	Same	No	1to3	20%	No;	No;
NH	5	X												X	No					Yes	Same	No	1to3	Different	Yes;	No;
NM	4to7	X	X					X							No					No		DK	1to3	Different	Yes;	No;

1	25	26	26	26	26	26	26	26	26	26	26	26	26	26	27	28	28	28	28	29	30	31	32	33	34	35
NV	5	X		X			X	X							No					Yes	Same	Yes	1to3	Same	Yes;	No;
NY	6 to 8	X	X												No					Yes	Same	Yes	1to3	20%	No;	No;
OK	10	X		X	X	X									No					Yes	Other	No	1to3	Other	Yes;	DK
PA	5 to 7	X	X					X		X		X		X	Yes			X		Yes	Same	Yes	5to7	Different	Yes;	No;
SC	DK														No					Yes	Same	No	1to3	20%	Yes;	No;
SD	5														DK					DK		Yes	1to3		DK	DK
TN	6 to 8			X						X				X	Yes	X				Yes	Same	Yes	1to3	Same	No;	No;
TX	5 to 7	X					X								No					No		Yes	1to3	20%	No;	No;
UT	6 to 10	X	X	X	X					X	X		X	X	No					Yes	Same	No	1to3	50%	No;	No;
VA	na	X	X	X				X		X	X				Yes	X				Yes	Other	No	1to3	Different	No;	Yes;
WY	7to10	X													Yes		X			Yes	Same	No	1to3	20%	No;	No;
AB	5	X		X	X	X	X	X				X			No					No		No	1to3	Other	No;	No;
BC	5	X		X	X		X	X						X	No					Yes	Same	No	1to3	Other	No;	No;
MNT	10yrs	X		X	X	X						X		X	No					Yes	Same	Yes	1to3	Same	No;	Yes;
NB	5	X													No					Yes	Same	No	1to3	Different	No;	No;
NS	7 to 10	X					X								No					Yes	Same	No	1to3	Same	No;	No;
ON	7 to 10	X		X				X						X	Yes	X				Yes	Same	Yes	1to3	50%	No;	No;
QB	7						X								No					Yes	Smaller	No	1to3	Same	No;	No;
SA	5	X													No					No		No	4to6	20%	No;	No;
AU	15 to 20	X													No					Yes	Same	No	1to3	50%	Yes;	No;
NZ - Cant	8 years			X	X	X	X	X		X	X		X	X	Yes					Yes	Same	Yes	1to3	20%	Yes;	No;
NZ - Well	8 years			X	X	X	X	X		X	X		X	X	Yes					Yes	Same	Yes	1to3	20%	Yes;	No;

State/Prov	AL	AZ	CA	DE	IA	IL	IN	KS	LA	MI	MN	MO	NC	ND	NH	NM
Question 37: Do you require training and/or certification for agency personnel?	DK	No;	No;	No;	No;	No;	No;	Yes;	No;	No;	No;	Yes;	No;	No;	No;	No;
Question 39: Do you require warranties in your microsurfacing projects?	No;	No;	No;	No;	No;	No;	Yes;	No;	Yes;	No;	No;	No;	No;	No;	Yes;	No;
Question 40: If yes, what is the length of the warranty and what criteria(threshold values) are required?							3 years		1to3						1 years	
Question 41: January																
Question 41: February																
Question 41: March		X							X							
Question 41: April		X	X				X		X							
Question 41: May	X	X	X	X	X	X	X		X				X	X		X
Question 41: June	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Question 41: July	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Question 41: August	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Question 41: September	X	X	X	X	X	X	X	X	X		X		X	X		
Question 41: October		X					X		X							
Question 41: November																
Question 41: December																
Question 42: Unit price-low bid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Question 42: Indefinite delivery/indefinite quantity												X				
Question 43: Square yard/square meter binder				X			X					X			X	
Question 43: Ton		X	X					X			X		X			X
Question 43: Gallon/liter	X				X				X	X			X	X		
Question 44: Reason Units of Area (SY/SM)				4		5	4					4			4	
Question 44: Units of Volume (Gal/Liter)		5			3	5			3	3			3	4		
Question 44: Units of Weight (ton/tonne)			3			5		3			3		2			4
Question 45: Units of Area: Square yard/meter	X											X	X		X	
Question 45: Units of Volume: Cubic yard/meter																
Question 45: Units of Weight: Ton/tonne		X	X	X	X			X	X	X	X			X		X
Question 46: Reason Units of Area (SY/SM)						5	4					4	2		4	
Question 46: Units of Volume (CY/CM)		5				5										
Question 46: Units of Weight (ton)			3	4	3	5		3	3	3	3			4		4
Question 47: Ave job length Center-line miles	10	10	6	2	7to10	Variable	10	10	2to15	9	25	2	7.2	10	10	8
Question 48:max ADT	4	4	5	2	3	3	5	5	5	5	5	5	3	5	2	5

1	37	39	40	41	41	41	41	41	41	41	41	41	41	41	41	42	42	43	43	43	43	44	44	44	45	45	46	46	46	47
NV	Yes;	Yes;	2					X	X	X	X	X				X					2						2			2.5
NY	No;	Yes;	1year					X	X	X	X	X				X			x				3			X			4	5to10
OK	DK	Yes;	1year				X	X	X	X	X	X				X			X		5	5	5			X	5	5	4	8
PA	No;	No;							X	X	X	X				X		X			4					X			4	2to6
SC	No;	No;					X	X	X	X	X	X	X			X		X			3			X			3			2
SD	DK	DK							X	X	X	X				X		X			5			X			5			
TN	No;	No;						X	X	X	X	X				X		X	X		3		2	X		X	3		2	15to20
TX	No;	Yes;	2year				X	X	X	X	X	X				X			X				4			X			4	5t015
UT	No;	No;						X	X	X	X	X				X		X			3			X			4			5to10
VA	Yes;	No;							X	X	X					X			X				4			X			4	5
WY	Yes;	No;							X	X	X	X				X			X				4			X			3	7
AB	No;	Yes;	1year					X	X	X	X	X				X														5to10
BC	DK	Yes;	1year						X	X	X					X		X			3			X			3			20
MNT	No;	Yes;	2yr						X	X	X					X			X				4			X			4	15km
NB	No;	Yes;							X	X	X					X		X			4			X			4			varies
NS	No;	Yes;	2yr						X	X	X	X	X			X		X			4			X			4			10
ON	No;	Yes;	2yr					X	X	X	X	X				X		X			4			X			4			5to10
QB	No;	Yes;	1yr								X					X		X			3			X			4			10
SA	Yes;	Yes;	1yr					X	X	X	X	X				X			X				4			X			4	4t07
AU	No;	Yes;	1yr	X	X	X								X	X	X					4	5	4		X		5	4	5	16to50
NZ - Cant	No;	Yes;	1yr	X	X	X	X						X	X	X	X		X			4									3
NZ - Well	No;	Yes;	1yr	X	X	X	X						X	X	X	X		X			4									3

State/Prov	Question 48:max ADT	Question 49: Type I	Question 49: Type II	Question 49: Type III	Question 50: Which gradation is most commonly used?	Question 51: Are any special gradations used?	Question 52: SS-1: (%)	Question 52: SS-1H: (%)	Question 52: CSS-1: (%)	Question 52: CSS-1P (%)	Question 52: CSS-1H: (%)	Question 52: CSS-1HP: (%)
AL	4						0	0	0	0	0	0
AZ	4		X	X	Type III	No	0	0	0	0	0	0
CA	5		X	X	Type III	No	0	0	0	0	0	0
DE	2											
IA	3		X		Type II	No	0	0	0	0	100	0
IL	3		X		Type II	No	0	0	0	0	0	100
IN	5		X		Type II	No	0	0	0	0	0	0
KS	5			X	Type III	No	0	0	0	0	0	0
LA	5				Other: Ple	Yes	0	0	0	0	0	100
MI	5		X		Type II	No	0	0	0	0	0	0
MN	5		X		Type II	No	0	0	0	0	0	0
MO	5			X	Type III	No	0	0	0	0	0	100
NC	3	X	X	X	Type II	No	0	0	0	0	0	0
ND	5		X	X	Type II	No	0	0	0	0	0	60
NH	2		X		Type II	No	0	0	0	0	0	0
NM	5		X		Type II	No	0	0	0	0	0	0

State/Prov	Question 52: CSS-1P: (%)	Question 52: CQS-1H: (%)	Question 52: CQS-1HP: (%)	Question 52: LMCQS-1H: (%)	Question 52: Ralumac™ : (%)	Question 52: Quick Set Mixing Grade: (%)	Question 53 How do you select the binder type:	Question 53: Traffic volume or ESALs	Question 53: Weather conditions in which seal	Question 53: Identified during design	Question 53: Compatibility with aggregate	Question 53: Past experience
AL	0	0	0	0	0	0					X	
AZ	0	0	0	0	0	100CRS-2P						X
CA	0	100	0	0	0	0						
DE												
IA	0	0	0	0	0	0					X	
IL	0	0	0	0	0	0						
IN	0	0	0	0	0	0						X
KS	0	0	0	0	0	0						X
LA	0	0	0	0	0	0					X	
MI	0	0	0	0	0	0						X
MN	0	0	0	0	0	0					X	
MO	0	0	0	0	0	0					X	
NC	0	0	0	0	0	0	X	X			X	
ND	0	0	40	0	0	0					X	
NH	0	100	0	0	0	0					X	
NM	0	0	0	0	0	0						X

State/Prov	Question 54: Do you use modifiers with your base asphalt or binder?	Question 55: Polymers	Question 55: Latex	Question 55: Additives	Question 55: Anti-stripping agents	Question 55: Styrene Butadiene Rubber (SBR)	Question 55: SBR- Polyisoprene	Question 55: SBS – Thermoplastic Elastomers	Question 56: What type of mixing equipment do you require?	Question 57: Do you require Com controlled mixing equipment?	Question 58: What type of mixture controls do you require?
AL	Yes	X							CSP	DK	Other
AZ	Yes	X							CSP	No	Rev
CA	Yes	X							Other	No	Rev
DE											
IA	Yes	X							CSP	No	Rev
IL	Yes		X						Other	Yes	Com
IN	Yes	X		X					Both	Yes	Com
KS	Yes	X							Both	No	Rev
LA	Yes	X		X					CSP	No	Rev
MI	Yes		X						Both	No	Other
MN	Yes		X						CSP	No	Rev
MO	Yes	X						X	Other	Yes	Com
NC	Yes	X							Both	DK	Com
ND	Yes	X							CSP	No	Rev
NH	Yes	X							CSP	No	
NM	Yes	X							CSP	No	

1	48	49	49	49	50	51	52	52	52	52	52	52	52	52	52	52	52	52	53	53	53	53	53	53	54	55	55	55	55	55	55	55	56	57	58
NV	5		X	X	Type III	No	0	0	0	0	0	0	0	0	0	0	0	0						X	Yes			X					CSP	No	Other
NY	5		X	X	Type II	No	0	0	0	0	0	0	0	0	100	0	0	0						X	Yes	X	X						Both	No	Rev
OK	5				Other: Ple	No	0	0	0	0	0	0	0	0	0	0	100	0						X	DK								CSP	DK	Com
PA	5		X		Type II	No	0	0	0	0	0	0	0	0	0	0	0	0						X	Yes		X						Both	No	Other
SC	4		X		Type II	No	0	0	0	0	0	0	0	100	0	0	0	0							Yes		X						Both	Yes	Com
SD	3				Other: Ple	No	0	0	0	0	0	0	0	0	0	0	0	0							DK								Other	DK	
TN	5				Other: Ple	Yes	0	0	0	0	0	0	0	0	100	0	0	0						X	Yes	X			X	X		X	CSP	Yes	Com
TX	5				Other: Ple	Yes	0	0	0	100	0	0	0	0	0	0	0	0						X	Yes	X							CSP	No	Rev
UT	5			X	Type III	No	0	0	0	0	50	25	0	0	0	0	25	0	X					X	Yes	X							Both	Yes	Com
VA	5				Other: Ple	Yes	0	0	0	0	0	0	0	100	0	0	0	0				X			Yes		X						Both	No	Other
WY	4			X	Type III	No	0	0	0	0	0	0	0	0	100	0	0	0						X	Yes	X							CSP	No	Rev
AB	5			X	Type III	No	0	0	0	100	0	0	0	0	0	0	0	0						X	DK								CSP	No	Rev
BC	4			X	Type III	No	0	0	0	100	0	0	0	0	0	0	0	0	X		X				Yes	X							Other	DK	
MNT	2			X	Type III	No	0	0	0	0	0	0	0	0	100	0	0	0						X	Yes	X							Both	Yes	Com
NB	5			X	Type III	No	0	0	0	0	100	0	0	0	0	0	0	0						X	No								Both	DK	
NS	5			X	Type III	No	0	0	0	0	0	100	0	0	0	0	0	0						X	Yes	X			X				Both	No	Other
ON	5		X	X	Type III	Yes	0	0	0	0	100	0	0	0	0	0	0	0						X	Yes	X							CSP	Yes	Com
QB	4		X		Type II	Yes	0	0	0	100	0	0	0	0	0	0	0	0					X		Yes	X							Both	Yes	Com
SA	4			X	Type III	No	0	0	0	0	0	0	0	0	100	0	0	0				X			Yes	X		X					Both	Yes	Com
AU	1				Other: Ple	No	0	0	0	0	0	0	0	0	0	0	0	0	X						Yes		X						CSP	No	Rev
NZ - Can	4		X		Type II	Yes	0	0	0	0	0	0	0	12	12	0	0	12							Yes					X			CSP	No	Rev
NZ - We	4		X		Type II	Yes	0	0	0	0	0	0	0	12	12	0	0	12							Yes					X			CSP	No	Rev

State/Prov	AL	AZ	CA	DE	IA	IL	IN	KS	LA	MI	MN	MO	NC	ND	NH	NM
Question 59: Static steel													X			
Question 59: Pneumatic-tired	X												X			
Question 59: Combination pneumatic/steel													X			
Question 59: Vibratory rollers																
Question 59: No rollers used		X	X		X	X	X	X	X	X	X			X	X	X
Question 60: Do you require any specific makes and models (proprietary specifications) for the microsurfacing equipment?	No	No	No		No		No	No	No	DK	No	No	No	No	No	No
Question 62 inspection of construction : Your agency	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Question 62: Private Consultant																
Question 62: Contractor																
Question 62: Other																
Question 63: Do you use an independent laboratory to evaluate microsurfacing mix design?	DK	No	No		No	No	No	No	No	No	No	No	No	Yes	Yes	No
Question 64: Does your agency have an incentive/ disincentive pay factor for the aggregate meeting the target submitted on the mix design	DK	No	No		No	No	No	No	No	Yes	No	No	No	No	No	No
Question 66 mix design tests: Residual Asphalt		X	X		X			X		X		X	X	X	X	
Question 66: Penetration		X			X							X			X	X
Question 66: Softening Point		X									X	X	X	X	X	X
Question 66: Sand equivalent		X			X				X	X	X	X		X	X	X
Question 66: Soundness					X				X	X	X			X	X	
Question 66: Abrasion resistance		X			X				X	X		X				
Question 66: Wet Stripping Test ISSA 114		X	X				X	X	X	X	X			X		
Question 66: Tests for the presence of clay			X								X		X			
Question 66: Percent Sodium Sulfate Loss					X							X				
Question 66: Consistency Test ISSA TB 106												X				
Question 66: Modified Cohesion test ISSA TB		X	X						X		X					
Question 66: Loaded Wheel Test ISSA TB 109		X	X						X			X		X		
Question 66: Wet-Track Abrasion Test ISSA TB 100		X	X				X	X	X	X	X			X		
Question 66: Set Time Test										X		X				
Question 66: Modified British Wheel Tracking																
Question 66: Cure Time Test ISSA TB 139		X					X					X				
Question 66: Lateral Displacement Test ISSA TB 147			X						X						X	
Question 66: Classification Test ISSA TB 144			X				X		X	X		X				
Question 66: Mix Time Test ISSA TB 113			X				X	X	X	X		X				
Question 66: Modified Cup Flow Test																
Question 66: TTI Mixing Test												X				

1	59	59	59	59	59	60	62	62	62	62	63	64	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
NV		X				No	X				Yes	No	X	X	X	X	X	X	X				X	X	X			X	X	X	X		
NY		X				No	X				No	No	X	X	X	X			X			X	X	X	X			X	X	X	X		
OK		X				No	X				No	No																					
PA		X				No	X				No	No							X				X						X	X	X		
SC					X	No	X				No	No	X																				
SD						DK	X				DK	DK																					
TN					X	No	X				No	No	X	X	X	X					X	X	X	X	X	X				X			
TX					X	No	X				No	No	X			X	X								X						X		
UT					X	No	X				No	Yes	X										X		X				X	X	X		
VA		X				No	X				No	No	X	X	X	X									X	X							
WY					X	No	X				No	Yes				X	X	X	X				X	X	X			X	X	X	X		
AB					X	No		X			No	No							X				X	X	X				X	X	X		
BC						DK	X				No	No	X	X	X	X	X		X	X													
MNT					X	No	X				No	Yes	X																				
NB						No	X				No	No	X		X				X				X	X	X				X	X	X		
NS		X	X			No			X		No	No	X	X	X	X		X	X						X				X	X			
ON					X	No	X				No	No											X	X				X	X	X	X		
QB			X		X	No		X			No	No	X	X	X				X			X	X						X				
SA					X	No	X				No	No	X	X	X	X		X	X	X					X	X		X			X		
AU		X				No	X				No	Yes																					
NZ - Cant					X	No			X		No	No	X	X		X									X								
NZ - Well					X	No			X		No	No	X	X		X									X								

State/Prov	Question 66: Compatibility of aggregate with binder	Question 67: Do you perform any field tests to monitor the quality of the mix?	Question 69: Do you take field material samples for compliance testing?	Question 70 who takes the samples: Agency	Question 70: General engineering Consultant	Question 70: Contractor	Question 70: Independent lab personnel	Question 71 where is the acceptance test conducted? : The pit/source	Question 71: The stockpile	Question 71: While transferring into the nurse units	Question 71: Just before it enters the microsurfacing paver mixing chamber	Question 71: DK	Question 72: Do you require calibration of mixing equipment?	Question 74: Do you require calibration of spreading equipment?	Question 77: Beyond calibration of mixing and spreading equipment, do you perform any other field tests to check material application rates?	Question 79 define "success": Meets expected service life	Question 79: Does not fail shortly after	Question 79: Achieves desired friction/skid number	Question 79: Qualitative measures — look, etc.	Question 79: Meets project specification	Question 80 What common distresses: Raveling	Question 80: Bleeding	Question 80: Corrugation	Question 80: Crack Reflection	Question 80: Streaking	Question 80: Transverse Joints	Question 80: Longitudinal Joints	Question 81 Rate Impact: Design Method	Question 81: Better Binder	Question 81: Better Aggregates	Question 81: Construction Procedure	Question 81: Contractor Experience	Question 81: QA/QC Program	Question 81: Preconstruction road preparation	Question 81: Selecting the right project
AL		Yes	Yes										DK																						
AZ		No	Yes	X		X			X				Cert	Cert	No	X		X	X	X				X	X			2	1	1	1	1	2	1	1
CA		No	Yes	X					X				Field	No	No		X		X	X					X			2	3	3	2	1	3	2	2
DE																																			
IA		No	Yes	X					X				Field	No	No					X				X		X		3	3	2	1	1	2	1	1
IL		No	No										Field	No	Yes						X		X	X				3	5	5	1	1	3	2	1
IN		No	No										Field	Field	No	X								X		X		3	3	3	3	3	3	3	3
KS		No	No										Field	Field	Yes	X		X		X				X				3	3	3	3	3	3	3	3
LA		Yes	Yes	X					X				Cert	Field	Yes	X	X	X	X	Lac	X			X				2	2	2	2	2	2	2	1
MI	X	Yes	Yes			X			X				Cert	Cert	Yes	X		X				X			X	X		2	2	2	1	1	2	3	3
MN		Yes	Yes	X							X		Field	No	Yes	X								X				2	2	2	2	1	3	2	1
MO	X	Yes	Yes	X					X				Cert	No	No	X	X	X	X	X							X	2	1	1	1	1	2	1	1
NC	X	DK	Yes	X								X	DK	DK	No	X	X	X	X	X					X	X	X	3	1	1	1	1	2	2	1
ND	X	No	Yes	X					X				Field	No	No	X								X	X			1	2	2	2	1	3	3	3
NH	X	Yes	Yes	X						X			Field	Field	No	X				X								3	3	3	3	3	3	3	3
NM		Yes	Yes	X					X				Field																						

1	66	67	69	70	70	70	70	71	71	71	71	71	72	74	77	79	79	79	79	79	80	80	80	80	80	80	80	81	81	81	81	81	81	81	81
NV		Yes	Yes			X		X					Field	Field	No		X				X	X			X			2	2	2	1	1	2	1	1
NY		No	Yes	X					X				Cert	No	No	X					X			X				2	2	2	2	1	2	2	1
OK		No	No									X	No	Field	No	X								X				3	3	3	3	3	3	3	3
PA		Yes	Yes			X			X				Field	Field	No					X		X			X			3	2	2	3	2	2	1	2
SC		Yes	Yes			X						X	Field	Field	No	X			X	X				X	X		X	2	2	2	2	1	3	2	1
SD		DK	DK										DK	Field	No	X	X	X	X					X		X		3	2	2	1	1	2	2	1
TN		No	Yes	X					X				Field	DK	DK	X					X			X				3	3	3	1	1	3	2	1
TX		Yes	Yes	X					X				Field	Field	No	X					X	X			X			2	3	3	2	1	2	2	1
UT		Yes	Yes	X					X				Cert	No	Yes	X		X		X				X				3	3	3	3	2	3	2	1
VA		Yes	Yes	X					X				Cert																						
WY		No	No						X				Field	Cert	Yes	X				X				X				3	3	3	3	1	3	3	1
AB		No	Yes			X		X					Field	Field	No	X	X		X	X	X			X				1	2	2	1	1	2	2	2
BC	X	No	Yes	X				X					Field	No	No		X		X	X	X				X			3	3	3	3	3	3	3	3
MNT		Yes	Yes	X							X		Field	Field	Yes				X	X	X	X	X		X			1	2	1	2	2	2	2	1
NB		No	No						X				Cert	Field	No	X			X					X				3	3	3	3	2	3	2	2
NS	X	No	No										No	No	No	X	X		X					X				2	2	2	1	2	3	4	2
ON		No	Yes			X			X				No	No	No	X	X		X	X						X		3	3	3	3	2	3	2	1
QB		Yes	No						X				Field	No	Yes	X			X							X		2	1	1	1	1	2	2	1
SA	X	Yes	Yes	X					X				No	No	Yes				X	X				X		X		3	3	3	1	2	3	2	1
AU		Yes	Yes			X			X				Field																						
NZ - Ca		No	Yes			X		X	X				Cert	Cert	No	X								X				2	2	3	2	2	2	2	1
NZ - We		No	Yes			X		X	X				Cert	Cert	No	X								X				2	2	3	2	2	2	2	1

State/Prov	Question 82: What is the most common public-user complaint about microsurfacing? (check one)	Question 83: How would you generally describe the pavement ride on roads after they receive a new microsurface	Question 84 microsurfacing failures: Weather	Question 84: Improper application rate	Question 84: Dirty or dusty aggregate	Question 84: Aggregate gradation	Question 84: Improper ambient and/or pavement temperature	Question 84: Improper binder viscosity	Question 84: Improper binder temperature	Question 84: Not applicable	Question 85 factors critical to required service life	Question 85: Underlying pavement structure	Question 85: Maintenance funding	Question 85: Friction loss	Question 85: Traffic	Question 85: Cold climate considerations	Question 86 methods do you use to maintain:	Question 86: Surface treatments (seal coat)	Question 86: Fog seal	Question 86: None
AL																				
AZ	None	Good	X	X	X							X								X
CA	Looses	Good		X				X			X	X					X	X		
DE																				
IA	Noise	Good					X				X					X	X			
IL	DK	Fair																		
IN	Noise	Fair										X					X	X		
KS	Noise	Good	X									X				X				
LA	None	Good									X	X		X			X	X		
MI	DK	Good								X	X									X
MN	App	Good						x			X						X			
MO	None	Good					X					X				X				X
NC	App	Good								X		X			X		X			
ND	Ride	Good			X						X	X			X		X			
NH	None	Excelle	X				X				X									X
NM																				

1	81	83	84	84	84	84	84	84	84	84	85	85	85	85	85	85	86	86	86	86
NV	None	Good	X													X	X			
NY	App	Good		X				X			X					X	X			
OK	Noise	Fair		X								X					X	X		
PA	Noise	Good		X		X			X					X			X			
SC	App	Good	X				X	X				X	X		X		X			
SD	Noise	Good	X								X	X	X	X	X					X
TN	Noise	Good													X					
TX	App	Fair		x							X	X					X		X	
UT	Noise	Good	X		X		X				X	X								X
VA		Good																		
WY	Other;	Good										X					X			
AB	None	Good						X				X				X	X			
BC	Looses	Good		X				X			X	X					X	X		
MN	None	Excellent		X					X		X	X								X
NB	App	Good					X									X	X			
NS	Noise	Good		X	X		X		X											X
ON	None	Good										X								X
QB	App	Good	X	X	X	X	X		X		X	X	X				X			
SA	App	Good		X								X								X
AU																				
NZ	None	Good	X	X		X					X	X			X			X		X
NZ	None	Good	X	X		X					X	X			X			X		X

APPENDIX B

Specification Content Analysis

This appendix contains the details of the content analysis of agencies that had specifications that were specifically identifiable as microsurfacing. Table B1 lists the agencies whose specifications were reviewed. Table B2 is the output from that analysis.

TABLE B1
AGENCY MICROSURFACING SPECIFICATION CONTENT ANALYSIS SUMMARY

Agency	Specification Title	Date	Remarks
Alabama	Paver-Laid Surface Treatment	2009	Microsurfacing included under this section title
FHWA EFLHD	Slurry Seal	2003	Microsurfacing included under this section title
Georgia	Microsurfacing	2001	
Kansas	Microsurfacing	2008	
Louisiana	Microsurfacing	2005	
Michigan	Microsurfacing	2003	
Minnesota	Microsurfacing	2009	
Missouri	Microsurfacing	2004	
Nebraska	Microsurfacing	2007	
New Mexico	Microsurfacing	2008	
Ohio	Microsurfacing	2010	
Oklahoma	Microsurfacing	1999	
Pennsylvania	Cold-Laid Latex-Modified Emulsion Pavement Course	2010	Microsurfacing included under this section title
Tennessee	Microsurfacing	2006	
Texas	Microsurfacing	2004	
Utah	Microsurfacing	2008	
Virginia	Latex-Modified Emulsion Treatment (microsurfacing)	1996	
Wyoming	Microsurfacing	2004	

TABLE B2
AGENCY MICROSURFACING SPECIFICATION CONTENT ANALYSIS

Agency	Binder	Residual Asphalt (%)	Mineral Filler (%)	Latex (%)	Aggre-gate	QC Sample	Type Mixer	Control	Cali-bration	Rollers
Alabama	CQS-1hp	6.0–7.5	1.0–2.0	3.0	TII	P	CSP	C	NS	S
FHWA	CQS-1h	5.5–10.5	0.0–3.0	3.0	TIII	S	CSP	C	C	N
Georgia	CQS-1hp	6.0–9.0	0.5–3.0	3.0	TIII	P	CSP	C	S	N
Kansas	CSS-1hm	6.5	1.0–3.0	NS	O	NS	CSP	NS	NS	N
Louisiana	CSS-1h	6.0–9.0	0.5–3.0	3.0	O	P	CSP	C	C	P
Michigan	CSS-1hm	7.0–8.5	0.25–3.0	NS	O	P	CSP	C	NS	N
Minnesota	CSS-1h	6.0–9.0	0.5–3.0	3.0	TII	P	CSP	C	C	N
Missouri	CSS-1h	5.5–10.5	0.0–3.0	3.0	TIII		CSP	C	C	N
Nebraska	CSS-1h	6.0–11.0	0.5–3.0	NS	O	P	CSP	C	S	N
New Mexico	CSS-1P	6.0–9.0	0.5–3.0	3.0	TII	S	CSP	C	C	N
Ohio	CSS-1h	7.0–8.5	0.25–3.0	NS	TIII	NS	CSP	MC	C	P
Oklahoma	CSS-1h	6.0–9.0	1.0–3.0	NS	O	PS	CSP	C	S	N
Pennsylvania	CSS–1h	6.0–7.5	1.0–2.0	3.0	TII	S	CSP	C	C	P
Tennessee		5.0–9.0	0.5–3.0	3.0	O	P	CSP	C	S	N
Texas	CSS-1p	6.0–9.0	0.5–3.0	NS	O	NS	CSP	C	S	N
Utah		5.5–9.0	NS	2.5	TIII	P	CSP	MC	S	N
Virginia	CSS-1h	6.5–8.5	0.25–3.0	3.0	O	P	CSP	MC	C	P
Wyoming	CQS-1hp	NS	NS	NS	TIII	P	CSP	C	S	N

Agency	Tack Coat	Rut filling	Compac-tion	Test Strip	Air Temps	Surface Temps
Alabama	Y	1/2	P	500	50	NS
FHWA	N	ND	T12	N	45	45
Georgia	Y	1/2	NS	N	50	50
Kansas	N	1/2	NS	N	60	60
Louisiana	Y	1/2	T24	1000	70	50
Michigan	N	ND	NS	N	45	45
Minnesota	Y	1/2	T24	1000	50	50
Missouri	Y	ND	T12	500	50	50
Nebraska	N	1.0	NS	N	50	50
New Mexico	N	ND	NS	N	50	NS
Ohio	Y	ND	T	1000	50	40
Oklahoma	N	ND	NS	TN	50	50
Pennsylvania	N	1/2	P	500	50	NS
Tennessee	Y	ND	T24	N	50	50
Texas	N	1/2	T	N	50	50
Utah	N	ND	NS	500	50	50
Virginia	N	1/4	Y	N	50	50
Wyoming	N	3/8	NS	TN	60	60

(*continued on next page*)

TABLE B2
(*continued*)

Testing Req'ts	**AL**	**FH**	**GA**	**KS**	**LA**	**MI**	**MN**	**MO**	**NE**	**NM**	**OH**	**OK**	**PA**	**TN**	**TX**	**UT**	**VA**	**WY**
Residual Asphalt Content	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pene-tration	X	X					X		X	X	X		X			X		
Softening Point		X			X				X	X	X		X			X	X	
Sand Equivalent	X	X		X		X	X	X	X		X	X	X		X	X		
Soundness		X		X								X			X		X	
Abrasion Resistance	X	X		X			X	X				X						
Wet Stripping			X		X	X	X	X			X		X	X		X		X
Clay												X				X		
% Sodium Sulfate Loss		X					X			X						X		
Consist-ency														X				
Modified Cohesion					X					X	X		X			X		X
Loaded Wheel			X		X					X			X	X		X		X
Wet-Track Abrasion			X		X	X	X			X	X		X	X	X	X		X
Set Time			X										X	X				X
Cure Time			X										X	X				X
Lateral Displace-ment			X		X									X		X		X
Class-ification					X	X	X				X		X	X		X		X
Mix Time			X		X	X	X				X		X	X		X		X
TTI Mixing															X			
Compa-tibility			X											X			X	

APPENDIX C

Microsurfacing Example Contract Clauses, Specifications, and Checklists

This Appendix contains copies of all the specifications, warranty clauses, etc., that are noted in the body of the report.

STATE OF OHIO
DEPARTMENT OF TRANSPORTATION
SUPPLEMENTAL SPECIFICATION 881
MICRO-SURFACING WITH WARRANTY
July 13, 1999

881.01 General. This work shall consist of constructing a cold laid polymer modified emulsified asphalt pavement course to fill ruts or provide one or more courses for existing pavements in reasonably close conformity with the lines shown on the plans or established by the Engineer and warrant it for 3 years.

881.02 Warranty Bond. When the successful Bidder provides the Department with the performance and payment bonds specified in 103.05, the successful Bidder shall also furnish a maintenance bond for a 3 year period in an amount equal to 75 percent of the contract amount.

The Surety that underwrites the maintenance bond is required to have an A.M. Best rating of "A -" or better. The cost of the maintenance bond shall be included in the pay item for the premium for the contract performance and payment bonds. The effective date of the maintenance bond is the date the Department's Form C-85 is issued for the pavement. The issuance of Form C-85 for the pavement shall occur within 30 days after all of the pavement items, including all pavement markings, are completed and the pavement is open to traffic in its permanent pattern. After Form C-85 is issued, the Department will notify the Surety and will establish all final quantities for the project and the project will be finalized using standard procedures. The maintenance bond expires 3 years after the issuance of Form C-85. The Contractor shall maintain the liability insurance specified in 107.14, insuring against Contractor or Contractor authorized operations negligently performed during the warranty period. This insurance shall be in effect throughout the warranty period. A copy of the Certificate of Insurance shall be sent to the District each year.

881.03 Materials, Mixture, Equipment, and Quality Control. The material shall meet or exceed the requirements of 406.02. The mixture used shall meet or exceed the requirements of 406.03. The equipment used for micro-surfacing shall be self-contained, self-propelled, continuous loading units designed for this purpose.
A minimum of two weeks before the start of production, the Contractor shall submit their material quality control plan and final mix design to the District Engineer of Tests and Laboratory. During production, any changes in the mix design shall also be submitted. These submittals are for verification of the above minimum requirements.

881.04 Surface Preparation. Surface preparation shall meet the requirements of 406.08 except as follows: The Contractor is responsible for all surface preparation including cleaning, removal of any paint or plastic markings, tack coat and any other work that may effect the performance of micro-surfacing. This surface preparation shall be included in the bid price of the 881. All visible joints and cracks longer than 2 feet (600 mm) in length shall be sealed in accordance with 825.04. This crack seal shall be included in the bid price for 881.

881.05 Test Strip. The Contractor shall construct a test strip to be evaluated by the Engineer. This test strip shall be 1000 feet (300 meters) long and consist of all of the application courses specified. The test strip shall be constructed at the same time of day or night the full production will be applied and may be constructed in 2 days or nights when multiple course applications are specified. The Engineer will evaluate the completed test strip after 24 hours of traffic to determine if the mix design is acceptable. Full production may begin after the Engineer accepts a test strip. If accepted, the cost of the test strip shall be paid for at the bid price for 881.
The test strip requirements will be waived if the following conditions are met:
1. The micro-surfacing will not be applied after September 30 or before May 1; and
2. The Contractor has constructed a test strip in the same construction season that was accepted by the Department and utilized the same materials and mix design.

881.06 Single Course Construction. The Contractor shall apply one course of microsurfacing mixture. The single course shall be completed using Gradation A aggregate applied at a minimum rate of 18 pounds/square yard (9.8 kg/m²) of dry aggregate or Gradation B aggregate applied at a minimum rate of 20 pounds/square yard (11 kg/m²) of dry aggregate.

881.07 Multiple Course Construction. The Contractor shall apply at a minimum, two courses of micro-surfacing mixture, each applied separately. The pavement cross section shall be restored by rut filling and or one or more leveling courses. This cross section correction shall be applied to the driving lanes only, prior to the surface course, which shall be applied to the entire paving pass, which may include the shoulder as directed by the plans. The total combined minimum application rate of 30 pounds/square yard (16.3 kg/m²) of dry aggregate shall be applied. The Department may specify a single course micro-surfacing on the shoulders when directed by the plans. Pavement segments greater than 1000 feet (300 meter) in length, with an average rut depth that exceeds 0.5 inch (12 mm), shall be rut filled. The Contractor shall use a microsurfacing mix with Gradation B aggregate applied with an approved rut box for each designated wheel track. A clean overlap and straight edges shall be required between wheel tracks. Each rutted wheel track shall be over crowned to allow for proper consolidation by traffic. For each 1 inch (25 mm) of applied mix, an additional 0.125 to 0.25 inches (3 to 5 mm) crown is required for traffic consolidation. If the Contractor applies leveling courses to profile the pavement, a micro-surfacing mix with Gradation A or B aggregate shall be used. The final surface course shall be completed using Gradation A aggregate, applied at a minimum application rate of 16 pounds/square yard (9 kg/m²) of dry aggregate or a Gradation B may be used with a minimum application rate of 20 pounds/square yard (11 kg/m²) of dry aggregate.

881.08 Finished Pavement. Traffic shall not be allowed on the mixture until it has cured sufficiently to prevent pickup by vehicle tires. The new surface shall be capable of carrying normal traffic within one hour after application without any damage occurring. Filled ruts shall be able to sustain traffic within 2 hours after placement. The Contractor shall protect the new surface from potential damage at intersections and driveways. Any damage by traffic to the mixture shall be repaired by and at the Contractor's expense. The finished surface should be free from excessive scratch marks, tears, rippling, and other surface irregularities. The surface area shall not contain transverse ripples or longitudinal streaks of 0.2 inch (5 mm) or more in depth, as measured with a 10 foot (3 meter) straight edge. The surface area shall not exhibit tear marks greater than 0.5 inch (13 mm) wide and or 4 inches (100 mm) long, or a tear mark greater than 1 inch (25 mm) wide and 3 inches (75 mm) long. The longitudinal construction joints and lane edges shall coincide with the proposed painted lane lines. Longitudinal joints shall be constructed with less than a 3 inch (75 mm) overlap on adjacent passes and no more than 0.5 inch (6.5 mm) overlap thickness as measured with a 10 foot (3 meter) straight edge. If applicable, place overlapping passes on the uphill side to prevent any ponding of water. Construct neat and uniform transverse joints with no more than a 0.2 inch (5 mm) difference in elevation across the joint as measured with a 10 foot (3 meter) straight edge. The edge shall be neat and uniform with no more than 2 inches (50 mm) of horizontal variance in any 100 feet (30 meters). The restored cross section of the pavement section between any edge line, lane line or center line as measured using a 10 foot (3 meter) straight edge transversely across the pavement shall not exceed 0.4 inches (10 mm), or 0.2 inches (5 mm) when measured with a 6 foot (1.8 m) straight edge. The preceding shall not apply to any pavement segment that is designed with a quarter crown cross slope or any area of the pavement within 1 foot (300 mm) of the edge line, lane line or center line. These cross section requirements do not apply to single course micro-surfacing.

881.09 Warranty Items and Work. The District Review Team (DRT) will review the pavement before June 1 each year during the warranty period to determine the performance of the micro-surfacing. Any areas of the pavement that do not meet the Threshold Levels specified in Table A, will have to be repaired by the Contractor. The District will notify the Contractor in writing of any required Warranty Work. Meeting the minimum requirements and guidelines of this specification are not to be construed as a warranty, expressed or implied, as to the materials properties and workmanship efforts required to meet the performance criteria specified.

TABLE A – DISTRESS TYPES AND THRESHOLD LEVELS	
Distress Type	**Threshold Level** (6)
Bleeding / Flushing (1)	300 square feet (28 m^2)
Surface Loss (2)	120 square feet (11 m^2)
Raveling (3)	300 square feet (28 m^2)
Rutting (4)(5)	0.25 inch (6 mm) continuous in any Segment.

Notes:

(1) Excess asphalt binder that creates a shiny, reflective condition that becomes tacky to the touch at higher temperatures.
(2) Loss of surface interlock by traffic wear, debonding, or delamination.
(3) "Moderate" level raveling as defined in the Strategic Highway Research Program (SHRP) "Distress Identification Manual for the Long-Term Pavement Performance Project" (SHRP-P-338).
(4) Measure the wheel path with a 4 foot (1.2 meter) straight edge.
(5) Only applies during the first 120 days after the Form C-85 is issued (see 881.02) or after any Warranty work.
(6) Based on 500 foot (150 meter) lane Segment. The beginning of a Segment is the beginning of any distress type.

The Contractor shall supply all material and labor to perform the Warranty Work at no additional cost to the Department. All Warranty Work shall be performed with material meeting the requirements of 881.03. The Contractor shall certify the component materials and designed mix meet or exceed the requirements of 881.03.

All Warranty Work shall be performed by August 31 of the same year as the review. If an appeal process uses the arbitration method, the District may revise the date for the completion of the Remedial Action for the appealed item. Any 1000 foot (300 meter) lane segment that has repairs or defects greater than 5 percent of the area shall be completely resurfaced with a full lane width of micro-surfacing meeting the requirements of 881.06 or 881.07. Only micro-surfacing shall be used for permanent repair and resurfacing areas. If the Department determines that immediate repairs are necessary, due to a potential hazard to the traveling public, the Department will notify the Contractor and establish a date that all repairs have to be finished. Temporary repairs may be performed using material approved by the Engineer. All temporary repairs shall be replaced with a permanent repair as soon as weather allows. The Contractor's construction traffic control for performing any work required or allowed by this specification during the warranty period shall be in accordance with current Department policy, the Ohio Manual of Uniform Traffic Control Devices for Streets and Highways, and subject to Department approval of the time the work will be performed. Any major change in Department construction traffic control policy will be considered a changed condition.

881.10 Appeal Process. The Contractor may appeal a finding of the DRT. Any appeal shall be submitted to the DCE, in writing, within 15 days after the written results of the DRT are given to the Contractor. The DCE will evaluate the Contractor's appeal. This evaluation will include reviewing the disputed area in the field and consulting with the Construction Section of the Office of Highway Management. The evaluation may also include reviewing test data, obtaining samples, or interviewing Department (District or Central Office) or Contractor employees.

The DCE's determination will be issued in writing to the Contractor within 45 days after the DCE receives the appeal. If the Contractor disagrees with the DCE's determination, the Contractor may appeal the determination using an arbitration method acceptable to the Department. The Department will agree, in all cases, to arbitration in the manner in which those methods are practiced by the Department. If the Contractor selects arbitration, written notice of this approach must be made to the DCE within 15 days of receipt of the DCE's determination. After written notice has been provided, the parties shall agree in writing to the Arbitrator and agree to share equally the fees of the Arbitrator. After the Arbitrator is given notice to proceed, the Arbitrator shall conduct an investigation and issue a determination within 45 days. The Arbitrator's determination will be limited to determining whether or not the pavement distress is or is not the fault of the Contractor.

881.11 Basis of Payment. The method of measurement shall be on an area basis [square yard (square meter)] in accordance with 406.12. The accepted quantities of microsurfacing will be paid for at the contract price for:

Item Unit Description

881 Square yard (square meter) Micro-surfacing with warranty, single course

881 Square yard (square meter) Micro-surfacing with warranty, multiple course

Missouri DOT Method Specification

SECTION 413.10 MICRO-SURFACING
413.10.1 Description. This work shall consist of producing and placing a mixture of cationic polymer-modified asphalt emulsions, mineral aggregate, mineral filler, water, and other additives as needed at locations shown on the plans or as directed by the engineer.

413.10.2 Material. All material shall be in accordance with Division 1000, Material Details, and specifically as follows:
Item Section
Emulsified Asphalt 1015
Aggregate 1002

413.10.2.1 Aggregate.
413.10.2.1.1 The mineral aggregate shall be flint chat from the Joplin area, an approved crushed porphyry or an approved crushed steel slag. Blast furnace slag may be used from sources with a documented history of satisfactory use and that have been previously approved by MoDOT for use in micro-surfacing. For non-traffic areas such as shoulders, the mineral aggregate may be crushed limestone or crushed gravel in accordance with Sec 1002.1. The aggregate shall be free of cemented or conglomerated material and shall not have any coating or detrimental material.

413.10.2.1.2 Blends of approved aggregate may be supplied provided:
(a) The individual aggregates are reasonably uniform in gradation and other qualities.
(b) The aggregates are uniformly blended with designated proportions into a separate stockpile prior to use. Aggregate may be blended directly into the supply truck provided the blending device has been calibrated, gate settings are unchanged, and belt samples indicate material gradation compliance.
(c) The proportion is not changed from the job mix formula during the course of placement.

413.10.2.1.3 The final aggregate, or blend of aggregates, shall be in accordance with one of the following gradations. In addition, the aggregate shall be ± 5 percent of the designated job mix gradation for all plus No. 200 (75 µm) material and within ± 2 percent for the minus No. 200 (75 µm) material.

Aggregate Gradation Requirements			
Type II		Type III/Type IIIR	
Sieve	Percent Passing	Sieve	Percent Passing
3/8 inch (9.5 mm)	100	3/8 inch (9.5 mm)	100
No. 4 (4.75 mm)	90 - 100	No. 4 (4.75 mm)	70 - 90
No. 8 (2.36 mm)	65 - 90	No. 8 (2.36 mm)	45 - 70
No. 16 (1.18 mm)	45 - 70	No. 16 (1.18 mm)	28 - 50
No. 30 (600 µm)	30 - 50	No. 30 (600 µm)	19 - 34
No. 50 (300 µm)	18 - 30	No. 50 (300 µm)	12 - 25
No. 100 (150 µm)	10 - 21	No. 100 (150 µm)	7 - 18
No. 200 (75 µm)	5 - 15	No. 200 (75 µm)	5 - 15

413.10.2.1.4 The final aggregate mixture shall have no oversize material when deposited at the stockpile site. If the stockpile area contains any particles exceeding the specified maximum sieve, all aggregate shall be screened again as the aggregate is loaded into the final placement machine.
413.10.2.2 Mineral Filler. Mineral filler shall be Type 1 Portland cement or hydrated lime, and shall be free of lumps or any other deleterious material.
413.10.2.3 Water. Water shall be potable and free of harmful soluble salts.
413.10.2.4 Additives. Any other material added to the mixture or to any of the component materials to provide the required properties shall be supplied by the emulsion manufacturer.
413.10.2.5. Material Acceptance. All aggregate shall be sampled, tested and approved by the engineer prior to use. Portland cement and hydrated lime may be accepted for use based on visual examination.
413.10.3 Job Mix Formula. The manufacturer of the emulsion shall develop the job mix formula and shall present certified test results for the engineer's approval. The job mix formula shall be designed in accordance with the International Slurry Surfacing Association (ISSA) recommended standards by an ISSA recognized laboratory. Mix acceptance will be subject to satisfactory field performance. The job mix formula, all material, the methods and the proportions shall be submitted for approval prior to use. Proportions to be used shall be within the limits provided in the table below. If more than one aggregate is used, the aggregates shall be blended in designated proportions as indicated in the job mix formula, and those proportions shall be maintained throughout the placement process. If aggregate proportions are changed, a new job mix formula shall be submitted for approval.

Material	Requirement
Type II Mineral aggregate, lbs/yd^2 (kg/m^2) dry mass, min.	10 - 20 (5.4 - 10.8)
Type III Mineral aggregate, lbs/ yd^2 (kg/m2) dry mass, min.	15 - 30 (8.1 – 16.3)
Type IIIR	As necessary
Polymer Modified Emulsion (residual), percent	5.5 to 10.5 by dry weight of aggregate
Mineral Filler, percent by mass of dry aggregate	0.0 to 3.0 by dry weight of aggregate
Additive	As required

413.10.3.1 All Types. The minimum dry mass per unit area will be based on a bulk specific gravity (BSG) of 2.65. In the event that crushed steel slag aggregate is used as a part of the blended aggregate or as the entire aggregate, the BSG of the final aggregate blend shall be determined and shown as part of the job mix formula criteria. If the BSG is different from 2.65 by more than 0.05, the above minimum masses shall be adjusted by dividing the specified unit mass by 2.65 and multiplying by the new BSG. (For example, for a new BSG = 3.15, the new minimum would be 3.15(10.8/2.65) = 23.8 lbs./sy (12.8 kg/m2)). These adjusted values shall be designated on the job mix formula and will apply in the field.
413.10.3.1.1 Type II. For Type II, if a specified thickness will be required, the amount of mineral aggregate per square yard (m2) shall be increased as necessary to obtain the thickness.
413.10.3.1.2 Type III. When specified, Type III shall be applied in two passes of approximately equal quantities, the first of which shall be to fill depressions and level the surface for the final pass.
413.10.3.1.3 Type IIIR. For Type IIIR mixes, there will be no minimum or maximum unit quantities. The contractor shall make the determination as to the amount necessary, except all depressed areas shall be filled level as specified. Type IIIR may be applied in more than one pass at the contractor's expense. Type IIIR shall not be added to Type II or Type III applications in the field, but shall be a separate application.
413.10.4 Equipment.
413.10.4.1 Mixing Equipment. The micro-surfacing mixture shall be mixed and laid by a self-propelled mixing machine. The mixing machine shall be able to accurately deliver and proportion the aggregate, mineral filler, water, additive and emulsion to a revolving multiblade dual mixer and to discharge the thoroughly mixed product. The machine shall have sufficient storage capacity for all components to maintain an adequate supply to the proportioning controls.
413.10.4.1.1 Individual volume or weight (mass) controls for proportioning each item to be added to the mix shall be provided. Each material control device shall be calibrated and properly marked. The calibration shall be approved by the engineer prior to proportion. Each device shall be accessible for ready calibration and placed such that the engineer may determine the amount of each material used at the time.
413.10.4.1.2 The mixing machine shall be equipped with a water pressure system and nozzletype spray bar to provide a water spray to dampen the surface when required immediately ahead of and outside the spreader box as required. No free flowing water shall be present.
413.10.4.2 Spreading Equipment. The micro-surfacing mixture shall be spread uniformly by means of a mechanical-type spreader box attached to the mixer. The spreader box shall be equipped with paddles or augers to agitate and spread the material uniformly throughout the box. The paddles or augers shall be designed and operated so all the fresh mix will be agitated to prevent the mixture from setting up in the box, causing side buildup and lumps.
413.10.4.2.1 The spreader box used for surface course construction shall be equipped with flexible seals in contact with the road to prevent loss of mixture from the box. The box shall be equipped with devices to adjust the thickness or grade of the surface and shall have a squeegee strike-off rear plate.
413.10.4.2.2 A secondary strike-off shall be provided to improve surface texture. The secondary strike-off shall have the same adjustments as the spreader box.
413.10.4.2.3 The spreader box used for rut-filling shall have two metal strike-offs, angled from each side toward the center at approximately 45 degrees. Interrupted flight augers shall be used ahead of the first strike-off plate to spread the mix and maintain laminar flow. The second strike-off plate shall be adjusted to produce the desired grade and depth. The first strike-off and augers shall be adjustable up and down in order to maintain a fairly uniform flow or roll of material in front of the second strike-off. A rubber squeegee shall be attached to the adjustable metal plate at the rear of the spreader box, behind the second strike-off, to texture the surface. The adjustable metal plate shall have sufficient clearance not to affect the grade established by the second strike-off.
413.10.5 Construction Requirements.
413.10.5.1 Test Strip. A test strip 500 feet (150 m) long and the width of one lane shall be provided. The test strip will be evaluated for 24 hours after placement and will be subject to approval from the engineer before any further production. If unsatisfactory, the test strip shall be removed and another strip placed for evaluation at the contractor's expense.
413.10.5.2 Surface Preparation. The surface shall be thoroughly cleaned of all vegetation, loose material, dirt, mud, and other objectionable material and shall be pre-wetted as required immediately prior to application of the micro-surfacing. All pavement marking shall be removed, maintained, and compensated for in accordance to Sec 620.
413.10.5.3 Application. The micro-surfacing mixture shall be spread to fill cracks and minor surface irregularities, and shall leave a uniform surface. No lumping, balling or unmixed aggregate will be permitted. Longitudinal joints shall be

placed on lane lines. Excessive overlap will not be permitted. The finished micro-surfacing shall have a uniform texture free of scratches, tears and other surface irregularities. The contractor shall repair the surface if any of the following conditions exist:

(a) More than one surface irregularity that is 1/4 inch (6 mm) or wider and 10 feet (3 m) or longer in any 100-foot (30 m) section of the micro-surfacing.

(b) More than three surface irregularities that are 1/2 inch (12 mm) or wider and more than 6 inches (150 mm) long in any 100-foot (30 m) section of the micro-surfacing.

(c) Any surface irregularity that is one inch (25 mm) or wider and more than 4 inches (100 mm) long. The finished longitudinal and transverse joints in the micro-surfacing shall be complete and uniform.

413.10.5.3.1 The contractor shall repair joints if any of these conditions exist:

(a) Build-up of micro-surfacing material at the joints.

(b) Uncovered areas at the joints.

(c) Longitudinal joints with more than 1/2 inch (12 mm) vertical space between the surface and a 4-foot (1.2 m) straightedge placed perpendicular to the joint.

(d) Transverse joints with more than 1/4 inch (6 mm) vertical space between the surface and a 4-foot (1.2 m) straightedge placed perpendicular to the joint.

413.10.5.3.2 The edges of the micro-surfacing shall follow the centerline, lane lines, shoulder lines and curb lines. The edges shall be repaired if the edges vary more than 3 inches (75 mm) from a 100-foot (30 m) straight line or from a 100-foot (30 m) arc on a curved section. The repaired surface shall be dense with a uniform texture.

413.10.5.3.3 Any successive passes shall be separated such that each layer placed undergoes approximately 12 hours of traffic for compaction and curing.

413.10.5.3.4 Type IIIR applications to raise shoulders or fill ruts shall be applied with the rut spreader box, and the contractor shall place a strip as designated in the contract documents to raise an area to match the surroundings. Rutting or traffic-bearing applications, excluding shoulders, shall be crowned 1/8 to 1/4 inch per inch (3 to 7 mm per 25 mm) of depth, to allow for compaction. Shoulder applications shall drain and slope uniformly downward to the shoulder point. A Type II or Type III application may follow as a surface course if specified in the contract documents.

413.10.5.3.5 Micro-surfacing shall not be placed over steel expansion plates.

413.10.5.3.6 When micro-surfacing is placed on concrete, a tack coat shall be applied first in accordance with Sec 407 and shall be given adequate time to break.

413.10.5.3.7 The micro-surfacing shall permit traffic operations on a 1/2 inch (12 mm) thick surface within one hour after placement at 75°F (25°C) and 50 percent humidity.

413.10.5.4 Weather Limitations. Micro-surfacing shall not be placed when either the air temperature or the temperature of the surface on which the mixture is to be placed is below 50°F (10°C), when it is raining, or when there is a chance of temperatures below 32°F (0°C) within 24 hours after placement. Temperatures shall be obtained in accordance with MoDOT Test Method TM 20.

413.10.5.5 Repair of Damaged Areas. Any traffic-damaged, marred areas or deficiencies as defined in Sec 413.10.5.3 shall be repaired by the contractor at the contractor's expense.

413.10.5.6 Incidental Construction. Areas that cannot be reached with the mixing machine shall be surfaced using hand squeegees to provide complete and uniform coverage. Utilities shall be protected from coverage by a suitable method. Work at intersections shall be done in stages, or blotter material shall be used to allow crossing or turning movements. Regardless of the method, no marred sections will be permitted.

413.10.6 Method of Measurement. Final measurement of completed Type II and Type III surface will not be made except for authorized changes during construction, or where appreciable errors are found in the contract quantity. Where required, measurement of Type II, Type III and Type IIIR micro-surfacing, complete in place, will be made to the nearest square yard (square meter). Final measurement of Type IIIR surface may be made as necessary to determine the actual areas placed. Field measurement will be based on the estimated width and length dimensions necessary to bring a designated area to a level plane, and not necessarily for the full rutted area. The revision or correction will be computed and added to or deducted from the contract quantity.

413.10.7 Basis of Payment. The accepted quantities of micro-surfacing will be paid for at the contract unit price for each of the pay items included in the contract. No additional payment will be made for removing and replacing test strips.

Checklists: Suggested Field Considerations for Microsurfacing

The following is an extract from Chapter 8: Micro-Surfacing of the NHI 2007 *Pavement Preservation Treatment Construction Guide*.

The following tables are guides to the important aspects of performing a micro-surfacing project. The tables list items that should be considered to promote a successful job. Thorough answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The field supervisor should understand its contents.

The tables are not intended to be a report but to draw attention to important aspects and components of the micro-surfacing project process. Some information may be product-specific and should be contained in the agency's relevant standard specifications, special standard provisions, or special provisions.

Preliminary Responsibilities		
Project Review	Is the project a good candidate for micro-surfacing? Should a micro-surfacing seal be used? What is the depth and extent of any rutting? How much and what type of cracking exists?	Is crack sealing needed? How much bleeding or flushing exists? Is the pavement raveling? What is the traffic level? Is the base sound and well drained? Have the project bid/plan quantities been reviewed?
Document Review	Bid specifications. Mix design information. Special provisions.	Construction manual. Traffic control plan (TCP). Material safety data sheet
Materials Checks	Has a full mix design and compatibility test been completed? Is the binder from an approved source (if required)? Has the binder been sampled and submitted for testing?	Does the aggregate meet all specifications? Is the aggregate clean and free of deleterious materials? Is the aggregate dry? Is the emulsion temperature within application temperature specifications?

Pre-Seal Inspection Responsibilities	
Surface Preparation	Is the surface clean and dry? Have all pavement distresses been repaired? Has the existing surface been inspected for drainage problems?

Equipment Inspection Considerations			
Broom	Are the bristles the proper length? Can the broom be adjusted vertically to avoid excess pressure?	Rollers (if used)	Do the roller tire pressures comply with the manufacturer's specification? What type roller will be used on the project (pneumatic-tired roller recommended)? Do the roller tire size, rating, and pressures comply with manufacturer's recommendations? Is the pressure in all tires the same? Do all tires have a smooth surface?
Calibration of Equipment	Has each machine been calibrated with the project's aggregate and emulsion? Who carried out calibration and what documentation has been provided?	Stockpile	Is the stockpile site well drained and clean? Does the Contractor have all of the equipment required at the stockpile site (loaders, tankers, and so on)?
Micro-surfacing Machine	Is the machine fully functional? Has the machine been calibrated for this project's aggregate and certified. Is the spreader rubber clean and not worn? Is the texture rubber clean and set at the right angle? Are all paddles in the pug mill intact? Is the spreader box clean and is it a micro-surfacing type box?	Equipment for continuous run operations	Is all equipment free of leaks? Are Flow boys or other nurse units clean and functional? Are there enough units to allow continuous running with minimal stops for cleaning box rubbers?

Site Considerations	
Weather Requirements	Have air and surface temperatures been checked at the coolest location on the project? Do air and surface temperatures meet agency requirements? Are adverse weather conditions expected? (High temperatures, humidity, and wind will affect how long the emulsion takes to break.) Is application of the micro-surfacing postponed if rain is likely? Are freezing temperatures expected within 24 hours of the completion of any application runs?
Traffic Control	Do the signs and devices used match the traffic control plan? Does the work zone comply with the agency's requirements? Are flaggers holding the traffic for reasonable periods of time? Are unsafe conditions, if any, promptly reported to a supervisor (contractor or agency)? Does the pilot car lead traffic slowly, 40 kph (24 mph) or less, over fresh micro-surfacing? Are signs removed or covered when they no longer apply?

Application Considerations	
Determining Application Rates	Have agency guidelines and requirements been followed? Have rut filling and leveling course application rates been calculated or estimated separately? Has a full mix design been done? Is more material applied to dried-out and porous surfaces? Is more material applied on roads with low traffic volumes? Is less material applied to smooth, non-porous, and asphalt-rich surfaces? Has moisture content been adjusted when calculating the application rate?
Project Inspection Responsibilities	
Micro-surfacing Application	Has a satisfactory test strip been done? Have field tests been carried out and are the results within specification? Are enough trucks on hand to provide a steady supply of material for the slurry machine? Does the application start and stop with neat, straight edges? Will an edge box be used? Is a rut box is used for ruts deeper than 12 mm (1/2”)? Is a leveling course used with a steel strike-off for ruts less than 12 mm (1/2”)? (Two courses are used where rut filling or leveling is employed.) Does the application start and stop on building paper or roofing felt? Are drag marks present due to oversize aggregate or dirty rubbers? Are rubbers cleaned regularly and at the end of each day? Does the machine follow a straight, even line with minimal passes to cover the pavement? Is the mix even and consistent? Are fines migrating to the surface? Is the application stopped as soon as any problems are detected? Does the application appear uniform? Does the surface have an even and uniform texture? Is the application rate checked based on amounts of aggregate and emulsion used? What is the time between spreading, foot traffic, and opening to vehicular traffic?
Rolling	Does rolling wait until the mat is stable? (Roller is 5-6 tonnes maximum) Is the entire surface rolled only once? Do the rollers travel slowly, 8-9 kph (5 mph) maximum?
Truck Operation	Are trucks staggered across the fresh seal coat to avoid driving over the same area? Do trucks travel slowly on the fresh seal? Are stops and turns made gradually? Do truck operators avoid driving over the micro-surfacing? Do truck operators stagger their wheel paths when backing into the paving unit?
Longitudinal Joints	Is the meet line overlapped a maximum of 75 mm (3 in)? Do the spreader box runners avoid running on the fresh mat? Are the meet lines at the center of the road, center of a lane, or edge of a lane, not in the wheel paths?
Transverse Joints	Do all applications begin and end on building paper? Is the mixture not too wet at start up? Is the building paper disposed of properly?
Brooming	Does brooming begin after the micro-surfacing can carry traffic? Does brooming dislodge the micro-surfacing? Is the surface raveling? (Follow-up brooming should be done if raveling is high or if traffic is high.)
Opening the Microsurfacing to Traffic	Does the traffic travel slowly — 40 kph (24 mph) or less over the fresh micro-surfacing? Are reduced speed limit signs used when pilot cars are not used? After brooming, have pavement markings been placed before opening to traffic?
Clean Up	Has all loose aggregate been removed from the traveled way prior to opening to traffic? Have all binder spills been cleaned up?

Troubleshooting

This section provides information to assist the maintenance personnel in troubleshooting problems with micro-surfacing, along with “dos and don’ts” that address common problems that may be encountered during the course of a project. The troubleshooting guide presented in Table associates common problems with their potential causes. For example, an unstable emulsion, too little water in the mix, incompatibility between the emulsion and the aggregate, and so on, may cause a slurry surface to delaminate.

Trouble Shooting Microsurfacing Job Problems										
	Problem									
Cause	**Brown**	**Whitish**	**Failure to Set**	**Poor Coating**	**Delayed Opening to Traffic**	**Breaks in Box**	**Ravels**	**Flushes**	**Delamination**	**Segregation**
Emulsion										
Emulsion unstable				•		•			•	
Emulsion too stable	•		•		•		•			
Emulsion too hot						•				
Too little emulsion	•			•			•			
Too much emulsion								•		
Mix										
Mix: Too many fines				•		•	•			
Mix: Too much cement		•				•				
Mix: Too little cement			•		•		•			•
Mix: Too little additive				•		•	•			
Mix: Too much additive		•	•		•		•			
Mix: Too much water	•		•		•		•	•		•
Mix: Too little water		•		•		•	•		•	
Mix: Aggregate/emulsion not compatible			•	•	•		•		•	•

Conditions										
Condition: Too hot	•			•		•	•	•		
Condition: Too cold			•		•		•		•	
Condition: Rain	•		•	•	•		•	•	•	
Condition: High humidity		•	•							
Surface										
Surface: Fatty			•					•		

In addition to the troubleshooting guide, the table below contains some commonly encountered problems and their recommended solutions.

Common Problems and Related Solutions	
Problem	**Solution**
Uneven Surface – Wash Boarding	Ensure the spreader box is correctly set up. Ensure the viscosity of the mix is not too high. Make adjustments so that the mix does not break too fast. Wait until the ambient temperature is lower. Use water sprays on the front of the spreader.
Poor Joints	Reduce the amount of water at start up. Use water spray if runners of spreader box are running on fresh material.
Excessive Ravel	Add cement and reduce additive so that the mix breaks and cures faster. Check aggregate to ensure the clay fines are not too high. Control traffic longer and at low speeds. Wait until fully cured before allowing traffic. Wait until mix is properly set before brooming or opening to traffic.

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation